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THE LIFE AND WORK OF DONALD OLDING HEBB, CANADA'S GREATEST PSYCHOLOGIST

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Donald Olding Hebb's lasting influence in psychology and neuroscience stems largely from his influential book, *The Organization of Behavior* (Hebb 1949a) in which he introduced the concepts of synaptic change and cell assemblies to explain the neural events underlying behaviour. Hebb's work revolutionized psychology by establishing a biological basis for psychological phenomena and expounding a neuropsychological theory which provided the structure for the development of the fields of cognitive and behavioural neuroscience. His ultimate fame could not have been predicted from his performance at Dalhousie University nor from his early career as a teacher. His career as a psychologist began as a night school student in psychology at McGill University in 1928. After completing his MA in psychology at McGill in 1932, he studied with Karl Lashley at the University of Chicago completing his PhD with Lashley at Harvard in 1936. For the next two years he conducted neuropsychological tests on the patients of Dr. Wilder Penfield at the Montreal Neurological Institute and from 1939 to 1942 was a professor at Queen's University in Kingston, Ontario. He spent the next five years studying emotionality in chimpanzees at the Yerkes Primate Center in Florida where he began to write *The Organization of Behavior*. Hebb became a professor of Psychology at McGill University in 1947 and head of his department in 1948 where he completed his book and directed an internationally recognized graduate program in physiological psychology. Elected President of the Canadian Psychological Association in 1952 and the American Psychological Association in 1960 he also became a Fellow of the Royal Societies of Canada and England. Late in his career, he was Vice Dean of Biological Sciences (1964-66) and then Chancellor of McGill University (1970-74). Upon retirement from McGill, he moved back to Nova Scotia and became a professor emeritus at Dalhousie University from 1978 until his death in 1985. During this time he wrote his last book, *Essay on Mind* (Hebb 1980a). He was inducted into the Canadian Medical Hall of Fame in October 2003.

L'influence durable de Donald Olding Hebb dans les domaines de la psychologie et de la neuroscience est en grande partie le résultat de son ouvrage prestigieux *The Organization of Behavior* (1949) dans lequel il présente les concepts de modification synaptique et de réseau neuronal pour expliquer les phénomènes neuronaux qui sous-tendent le comportement. M. Hebb a révolutionné le domaine de la psychologie en établissant une base biologique pour des phénomènes psychologiques et en expliquant une théorie neuropsychologique qui a fourni la structure nécessaire au développement des domaines de la neuroscience cognitive et comportementale. Sa renommée n'aurait pu être prédite à partir de sa performance à l'Université Dalhousie ou de son poste d'enseignant au début de sa carrière. Sa carrière dans le domaine de la psychologie a débuté lorsqu'il a commencé à suivre des cours du soir dans le domaine à l'Université McGill en 1928. Après avoir obtenu une maîtrise en psychologie à l'Université McGill en 1932, il a étudié aux côtés de Karl Lashley à l'Université de Chicago pour finalement obtenir un doctorat avec M. Lashley à l'Université Harvard en 1936. Au cours des deux années suivantes, il a effectué des tests neuropsychologiques sur les patients du docteur Wilder Penfield à l'Institut neurologique de Montréal. De 1939 à 1942, il a été professeur

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à l'Université Queen's, à Kingston en Ontario. Il a passé les cinq années suivantes à étudier les émotions chez le chimpanzé au Yerkes Primate Center en Floride. C'est au cours de cette période qu'il a commencé à rédiger *The Organization of Behavior*. M. Hebb a ensuite occupé un poste de professeur de psychologie à l'Université McGill en 1947 et il a été nommé chef du département de psychologie en 1948, poste dans le cadre duquel il a dirigé un programme d'études supérieures de renommée internationale en psychophysiologie. C'est à cette période qu'il a terminé son ouvrage prestigieux. Élu président de la Société canadienne de psychologie en 1952 et de l'American Psychological Association en 1960, il a également été un Membre de la Société royale du Canada et un membre de la Royal Society of England. Vers la fin de sa carrière, il a occupé le poste de vice-doyen des sciences biologiques à l'Université McGill (de 1964 à 1966) puis de chancelier de cette même université (de 1970 à 1974). Au moment de sa retraite de l'Université McGill, M. Hebb est retourné en Nouvelle-Écosse. Il a été professeur émérite à l'Université Dalhousie de 1978 jusqu'à sa mort en 1985, période durant laquelle il a rédigé son dernier ouvrage *Essay on Mind* (1980a). Il a été intronisé au Temple de la renommée médicale canadienne en octobre 2003.

1. Hebb's accomplishments

The accomplishments that made Donald Olding Hebb famous in psychology in Canada and the rest of the world are of three types. First, was his determination to demonstrate, in theory and by experiment, that each type of behaviour studied by psychologists was the result of brain function. In providing arguments for this proposition, Hebb developed a theory that integrated data from many disparate areas of psychology into a single neuropsychological theory. Second, Hebb created research areas in psychology that had not existed before. These included the effects of environmental enrichment and sensory deprivation on behaviour and the idea of perceptual learning. His two most fundamental concepts, the ideas of synaptic change and cell assemblies led to a physiological model of the cognitive functions underlying motivation, emotion, thought and consciousness. Third, through his teaching of undergraduate and graduate students in the Psychology Department at McGill University, Hebb founded the areas of Behavioural and Cognitive Neuroscience, which shaped the development of psychology and neuroscience in Canada. Hebb's ideas were promoted by his students as they built laboratories in universities across Canada and the world. Today the terms "Hebb synapse", "Hebbian cell assembly" and "Hebbian learning mechanism" are basic concepts, not only in psychology and neuroscience, but also in physics and computer science, where they are used in computer models of learning and memory.

2. Hebb's family

Donald Olding Hebb was born into a family whose roots are as old as British Nova Scotia. Much of what we know about his life comes from his published autobiography (Hebb 1980b) and an unpublished autobiography (Hebb 1980c). Hebb's great-great-great grandfather, Johann Adam Heb (1738-1803) emigrated to Nova Scotia from what is now Germany at the age of 12 and settled in Lunenburg County in 1753 (Teal 1994). All of the Hebbs in Nova Scotia are descended from Adam Heb. Hebb's grandfather, Solomon Hebb (1839-1935) was a millwright and his children were the first

of the Hebbs to attend Dalhousie University. Hebb's father, Arthur Morrison Hebb (1872-1959) received a BA (1899) and an MD (1902). His brother, Thomas Carlyle Hebb (1878-1938) received a BA (1900), MA (1901) and BSc (1902) from Dalhousie and went on to receive a PhD in Physics from the University of Chicago (1904). He taught Physics at the University of British Columbia (UBC) from 1916 until his death in 1938. His sister, Bertha Boyd Hebb (1869-1954) was the first woman from Lunenburg County to graduate from Dalhousie University, receiving her BA in 1894 and MA in 1898. She became a teacher and spent most of her career in South Africa.

Hebb's mother, Mary Clara Olding (1870-1921) was descended from Nicholas Purdue Olding (1751-1845), who was the first practising lawyer in Pictou County and came to be known as "the father and grandfather of the bar" (Olding 1976, Patterson 1955). She attended the Pictou Academy and entered medical school at Dalhousie University in 1892, receiving an MD in 1896. She was the third woman to receive an MD from Dalhousie University (MacLeod 1990) and had a medical practice in Saint John, New Brunswick, before marrying Arthur Morrison Hebb in 1903 and joining him in his practice in Chester, Nova Scotia.

Donald Olding Hebb was born on 22 July 1904, the first of four children (see Fig 1); he had two brothers, Andrew (1905-2005) and Peter (1909-1955), and a sister, Catherine (1912-1978). All of the Hebb children went on to pursue distinguished careers. Andrew received a BA (1925) and a law degree (1927) from Dalhousie and became a journalist and then the founding chief executive of the Co-operators Insurance Company. Peter

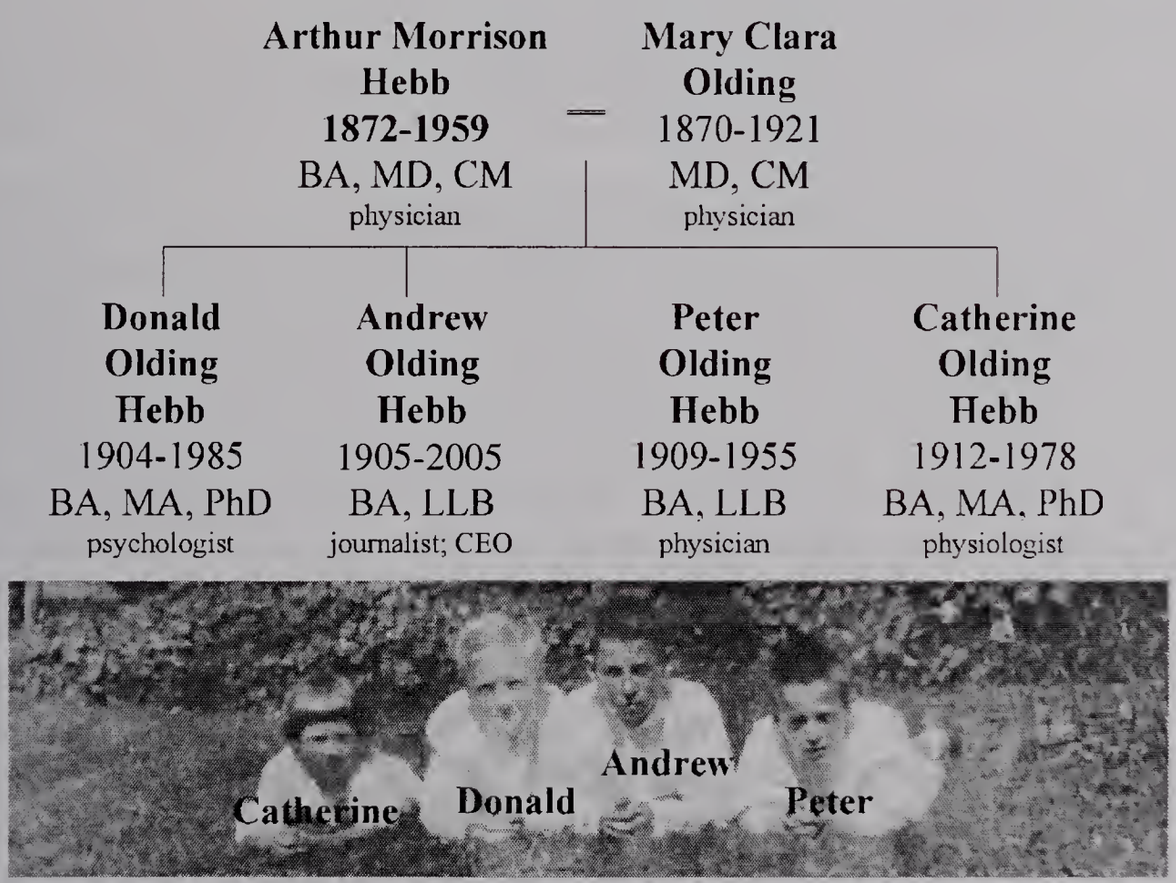

Fig 1. Hebb and his siblings. Hebb's family all received degrees from Dalhousie University and went on to distinguished careers. From Gordon Hebb.

received an MD (1934) from Dalhousie and was a physician in Dartmouth, Nova Scotia. Catherine received a BA in Biology (1932) and an MA in Pharmacology (1933) from Dalhousie and a PhD in Physiology from McGill University (1937), where she studied the physiology of the digestive system in the laboratory of Dr. Boris Babkin. She started teaching in the Department of Physiology at the University of Edinburgh in 1938 and spent a year at the physiological laboratory at Cambridge University (1945), where she began her research on the biosynthesis of acetylcholine. In 1952 she joined the Institute of Animal Physiology at Babraham, Cambridge, and continued to work on acetylcholine until the end of her career (Silver 1993).

3. Hebb's education in Nova Scotia

As his brother Andrew was ill as a child, they were both taught at home by their mother, who was an advocate of the Montessori method (Hebb 1980b). Donald was an avid reader and, after entering the Chester School in the second grade at 8 years of age, he was rapidly promoted. He completed grades 2, 3 and 4 in his first year at school and then grades 5 and 6 in his next year and reached the ninth grade when only 12 years old (Hebb 1980b). School work came easily to him and, after winning a school spelling competition in the seventh grade, he did little studying. As the result of lax teaching and poor study habits, he, and most of his classmates, failed grade eleven and had to repeat the year. In 1920, the family moved to Dartmouth, Nova Scotia where Donald and Andrew completed grade 12 at the Halifax County Academy. The first major crisis in his life occurred in July 1921, when his mother died of cancer, just before he and Andrew entered Dalhousie University. Although his father wanted him to take math and physics like his uncle, Thomas Carlyle Hebb, Donald entered the Faculty of Arts and majored in English and philosophy, with the intention of becoming a novelist (Hebb 1980b).

When Hebb was a student, psychology was taught in the Philosophy Department at Dalhousie. A separate Psychology Department was not formed until 1948. We do know, however, that Hebb was exposed to psychology in two of his Philosophy classes: Philosophy 1 (Logic and Psychology) taught by H.L. Stewart, and Philosophy 9 (Experimental Psychology), taught by Norman J. Symons. During his last two years at Dalhousie, Hebb worked on the Dalhousie Gazette student newspaper, in which he published a number of poems. He was also the historian of the class of 1925 (Hebb 1925). After graduating, he took summer classes to obtain a teaching certificate from the Provincial Normal School in Truro, Nova Scotia, and became the principal of his old school in Chester.

4. Hebb as a teacher and graduate student in Montreal: 1926-34

After teaching in Chester for only one year, Hebb spent the summer of 1926 working as a laborer on a farm in Alberta, where it is thought that he contracted tuberculosis. Hebb then moved to Montreal, where he became a teacher in Verdun. During this time, he met Professor W.D. Tait, the

Head of the Psychology Department at McGill, and attended Dr. Tait's night school class in psychology for teachers. From 1928 to 1930, Hebb taught at Rushbrooke School in Verdun, and was a part-time graduate student in psychology at McGill under the supervision of Professor Chester Kellogg. During this time Hebb started his educational experiment. As a teacher and principal, Hebb found that students of all intellectual abilities were failing in school. He decided to change the school procedures to facilitate education and persuade the children that schoolwork was a privilege. He gave the students interesting things to do in class and no homework. Students were not punished for inattention and those who disrupted the class were sent outside to play. He described this experiment in a teacher's journal (Hebb 1930) and continued with it for four years.

During the 1930-31 school year, Hebb was bedridden with tuberculosis of the hip, which left him with a permanent limp. He convalesced at his father's home in Dartmouth, Nova Scotia, and met Isabel Clark, the daughter of a Halifax clergyman, whom he married in 1931. While he was bedridden, Hebb studied Sherrington's *Integrative Action of the Nervous System* and Pavlov's *Conditioned Reflexes*, and wrote a theoretical MA thesis (Hebb 1932). This thesis is of interest because it contains Hebb's first thoughts on the nature of synaptic activity during conditioning (Brown & Milner 2003). It was passed by two examiners, Professor Kellogg of the Psychology Department and Professor Boris P. Babkin of the Physiology Department at McGill. Babkin had worked with Pavlov in St. Petersburg and held a Chair in Physiology at Dalhousie (1924-28) before becoming a Research Professor in Physiology at McGill (Babkin 1942). After the completion of his MA thesis, Hebb worked in Babkin's laboratory, studying Pavlovian conditioning with Leonid Andreyev who had also worked with Pavlov.

Hebb continued his teaching career while he was working on his PhD at McGill, but 1933-34 was a terrible year for him and he decided to leave Montreal. First, the Protestant School Board of Montreal terminated his educational experiment (Hebb 1980b). This appears to have coincided with the appointment of a new school inspector in Verdun. Second, he became disillusioned with Pavlovian conditioning procedures and his graduate studies at McGill. Most of the faculty in Psychology were engaged in Educational Psychology and Intelligence Testing, whereas Hebb was becoming increasingly interested in Physiological Psychology. Third, Hebb and his wife were in a car accident near New Glasgow, Nova Scotia and she died on his birthday in 1933 (Hebb 1980b).

5. PhD research with Karl Lashley: 1934-37

Following the advice of Professor Babkin, Hebb went to study at the University of Chicago in July 1934 with Lashley, the world's leading Physiological Psychologist, who had just published an influential book on the neural basis of intelligence (Lashley 1929). Lashley had been the president of the American Psychological Association, and his presidential address summarized the state of the art in the physiological study of behaviour

(Lashley 1930). In Chicago, Hebb had classes with some of the foremost Professors of Psychology in America. He took Physiological Psychology from Karl Lashley, Psychological Testing from Forrest A. Kingsbury, Factor Analysis from L.L. Thurstone, Learning from Harvey A. Carr (the Head of the Psychology Department) and a seminar in Gestalt Psychology from Wolfgang Kohler. He also had a course in physiology from Nathaniel Kleitman and a course in anatomy from C.J. Herrick. During the time that Hebb was at Chicago it was the centre of Functional Psychology, with a focus on the biological basis of behaviour (Dewsbury 2002, Kingsbury 1946), an approach that he was to follow for the rest of his career.

Only a year after Hebb arrived in Chicago, however, Lashley accepted a position at Harvard University and Hebb moved with him to Harvard to complete his PhD. At Harvard, Hebb worked on the visual abilities of rats reared in the dark (Hebb 1936) and received his degree in 1936. For the next year, Hebb worked as a Research Assistant for Lashley and as an Instructor in Introductory Psychology for Professor E. G. Boring. During this year, Hebb published his PhD research (Hebb 1937) and completed the research that he had started in Chicago on field orientation in rats (Hebb 1938). In 1937, Hebb married Elizabeth Donovan, who had studied Education and Sociology at the University of Chicago. She became the mother of his two daughters, Jane and Mary Ellen.

6. Neuropsychology at the Montreal Neurological Institute: 1937-39

In 1937, Hebb's sister Catherine, who was a PhD student with Babkin at McGill University, informed him that Wilder Penfield, the founder of the Montreal Neurological Institute (MNI), was looking for someone to study the psychological effects of his neurosurgical procedures. Penfield was the leading neurosurgeon of his day, and specialized in surgery for epilepsy (Bell 1977, Feindel 1992). Hebb was appointed as a Rockefeller Fellow and Lecturer in Clinical Psychology at the MNI in 1937 and worked with patients who had temporal lobe and frontal lobe surgery. Hebb's most complete study was of patient KM, who was tested before and after a frontal lobotomy. Much to his surprise, Hebb found little effect of the surgery on KM's scores on the standardized psychological tests available at the time (Hebb & Penfield 1940) and he concluded that the removal of large amounts of frontal lobe tissue either had no effect on the mental abilities of the patient or that the tests available were not sensitive enough to detect the effects of the surgery (Hebb 1939a, Hebb & Penfield 1940).

Hebb's experience in testing patients at the MNI led him to develop a theory about the nature of intelligence and how it should be tested. First, he found that the Stanford Binet and the Wechsler Intelligence tests were inadequate for use with adult patients who had low verbal ability and who did not speak English (Hebb & Morton 1944). So, along with professor N.W. Morton of the McGill Psychology Department, Hebb began to develop two new tests: the verbal Adult Comprehension Test and the non-verbal Picture Anomaly Test (Hebb & Morton 1943). Second, Hebb observed that

lesions of different brain areas produced different cognitive impairments. He began to believe that intelligence was not a unitary entity but a complex phenomenon, whose multiple components could be differently affected by cerebral lesions. As a result he developed the idea that rather than measuring overall intellectual change, one should determine the specific aspects of intelligence affected by brain lesions using specific neurological tests (Hebb 1939b). Third, Hebb came to believe that intelligence had two components: a fixed or biological component and a variable component that could be influenced by environmental experience (Hebb 1942). Fourth, Hebb found that the age at which a brain injury occurred was important in determining its effects on intelligence. Certain abilities were affected more by early than late injury, while the age at injury was not important for other abilities (Hebb 1939b, 1942). These findings, important for the development of Hebb's ideas on the neural control of behaviour, surfaced many times throughout Hebb's career.

7. Hebb at Queen's University: 1939-42

When his Fellowship at the MNI ended in 1939, Hebb took a position as a Lecturer in the Department of Mental and Moral Philosophy at Queen's University. Here he taught Philosophy 2 (Psychology), an elementary survey of mental life, Philosophy 30 (Problems in Psychology) in which students conducted "a specific experimental problem of a minor character", Philosophy 4 (Contemporary Psychology), a survey of present-day psychology, and Philosophy 15 (Experimental Psychology) and also had students conduct laboratory experiments (Queen's University 1940-41).

Despite this heavy teaching load at Queen's, Hebb managed to publish his studies on the effects of brain lesions at different ages (Hebb 1942), a review of frontal lobe function (Hebb 1945a) and also completed two research projects with his students. Hebb & Williams (1946) designed a variable path maze and this Hebb–Williams maze has since been used in a plethora of comparative studies of learning in animals and humans (Shore et al. 2001). Hebb & Foord (1945) tested and refuted the Gestalt hypothesis of dynamic activity within the memory trace. However, Hebb was not highly paid at Queen's and had to earn extra money to support his family by teaching summer school and marking extramural essays in addition to his regular load of four full courses (Hebb 1980d).

While Hebb was at Queen's University, Professor Humphrey, the Head of the Psychology Department at Queen's, and Professor Bott, from the University of Toronto, brought together a number of psychologists to assist the war effort and this group founded the Canadian Psychological Association (CPA) in 1940. The first accomplishment of this group was the development of the M-test, an Army classification test for new recruits developed primarily by N.W. Morton (Ferguson 1993). The first issue of the Bulletin of the Canadian Psychology Association (the forerunner of the Canadian Psychologist) was published in October 1940 with Hebb as the editor from December 1940 until 1942. When the first meeting of the CPA was held

at McGill University in December 1941, Hebb (1941) presented a paper entitled "Higher level difficulty in verbal test material".

Hebb was promoted to Assistant Professor at Queen's in 1941, but even with a increase in salary to $2400 per year, he was not able to support his family of four (his second daughter was born in Kingston in 1941). Thus, Hebb began to search for a better paying position that would allow him more time for research.

8. Hebb at the Yerkes Primate Research Laboratory: 1942-47

When Karl Lashley succeeded Robert Yerkes as the director of the Yale Primate Laboratories at Orange Park, Florida in 1942, he offered Hebb a position as a research scientist at a salary of $4000 per year. The position included an appointment in the Department of Psychology at Harvard, one month of vacation per year, $200 per year for travel and expenses for scientific meetings. This was exactly the sort of position that Hebb was seeking and he moved to Florida in September 1942. There he was employed as a Research Associate (1942-45) and then as a Harvard University Research Fellow (1945–1947). The travel money was spent on trips to Montreal to continue his collaboration with Penfield.

During his years in Florida, Hebb studied fear and anger in chimpanzees (Hebb 1945b, 1949b) and related these findings to human emotionality (Hebb 1946, 1947a). He also studied the behaviour of dolphins (McBride & Hebb 1948) and continued his work on the development of rat intelligence. To determine the effects of early experience on learning, Hebb and his daughters reared rats as pets at home and showed that this enriched experience resulted in improved maze learning in adulthood (Hebb 1947b). These studies formed the basis of studies on the effects of environmental enrichment on behaviour and neural development (Krech et al. 1962) that has become one of the most important concepts in developmental psychology and continues to influence research on neural and behavioural development (van Praag et al. 2000).

9. Writing *The Organization of Behavior*: 1944-1949

During his years in Florida, Hebb completed the first five chapters of the manuscript of a book, eventually published under the title *The Organization of Behavior*, in which he outlined an entirely new way of understanding behaviour in terms of brain function. Hebb discussed how he came to write *The Organization of Behavior* in two autobiographical memoirs (Hebb 1959, 1980b). In short, his previous research on the effects of brain lesions at different ages on intelligence (Hebb 1942) led him to the conclusion that intelligence must be a product of both innate ability and learning experience. He began to ask how the concepts, modes of thought, and ways of perceiving, which constitute intelligence, could be conceived in terms of neural mechanisms (Hebb 1980b).

Hebb made notes for *The Organization of Behavior* between June 1944 and March 1945. These notes outline a set of physiological explanations for psychological processes such as attention, perception and learning (Hebb

1945c). It is in these notes that Hebb worked out the basic propositions of his neuropsychological theory, which he said was "not merely a translation [of psychological data] into physiological terms, but suggests the basis of considerable synthesis and makes possible an intelligible formulation of the problems of attention and thought, as a function of central processes" (Hebb 1945c).

There were a number of problems that Hebb had to overcome in order to develop his neuropsychological theory and he mentions three of these in his notes: the inter-relatedness of psychological concepts; the assumption that behaviour is under sensory control; and the lack of neurophysiological data. He dealt with these problems by developing a set of postulates that became the building blocks of his theory. These were: that perception required learning, that synaptic change could account for learning, that neural activity could be separated from sensory input and that both perception and learning could be accounted for through the development of cell assemblies.

The idea that perception required learning was stimulated by the work of von Senden (1932, 1960) on the development of visual ability in congenitally blind people after surgical operations which enabled them to see for the first time. Hebb used the case studies in this book and the work of Riesen (1947), on monkeys reared in the dark, to argue that perception relied on learning. It was only after he developed the idea of perceptual learning that Hebb returned to his own PhD thesis and understood how he had mis-interpreted his own results. Hebb (1937) had concluded that visual ability of rats was innate as rats reared in total darkness could discriminate between two figures, but in his Precis (Hebb 1945c), he reported that the rats reared in darkness took much longer to make this discrimination than rats reared in the light as they had to undergo a period of perceptual learning once they were removed from the darkness (Hebb 1949a). Although Wertheimer (1951) disagreed with Hebb's interpretation of von Senden's results, they were crucial to Hebb's development of the concept of the cell assembly and the idea that perceptual organization occurs through a process of learning.

Hebb relied on two books for his background information on learning theory and the physiology of behaviour, Hilgard & Marquis (1940) and Morgan (1943), both of which explained the synapse and neural connections as described by Lorente de No (1938). These books determined how Hebb thought synapses functioned. When Hebb was developing his ideas about the neural basis of behaviour in 1944 and 1945, there were no textbook descriptions of neurochemical transmission in the CNS and thus no neurotransmitters to discuss. Hebb, like everyone else, was working only with the idea of electrical transmission in the cortex. This meant that the brain was envisioned as a series of electrical circuits in which changes in "bio-electric fields" were thought to underlie learning (Hilgard & Marquis 1940). The neurochemical synapse was not formally acknowledged until Eccles published his seminal paper (Eccles et al. 1954) and it was only

after this that Eccles came to believe that synaptic transmission in the CNS could be chemical as well as electrical (Eccles 1976, 1982). Thus, Hebb's belief that synaptic change accounted for learning came from these books; he did not claim that the "Hebb synapse" idea was his own.

It was from Lorente de No's (1938) theory of recurrent (reverberating) nerve circuits that Hebb developed his idea of "cell assemblies". The concept of the cell assembly, with its reverberating circuits, meant that neural activity could continue in the absence of an external stimulus. Eccles had developed the idea of inhibitory synapses (Brooks & Eccles 1947) but, although he wrote an essay on inhibition in the nervous system in 1934 (Hebb 1934), he did not incorporate the concept of inhibition into his theory; it had to wait for Milner's (1957) revision. The cell assembly theory provided a neural explanation for perceptual processes and learning as both relied on external input to develop a mental image (cell assembly). The concept of the phase sequence allowed cell assemblies to communicate and thus provided the neural basis for thought and other higher order mental processes.

Hebb completed the first five chapters of *The Organization of Behavior* in Florida and sent them to Edwin G. Boring at Harvard, Lashley and others for comment. He invited Lashley to be a co-author of the book, but Lashley was not impressed with the manuscript and declined co-authorship. Despite Lashley's negative opinion, Hebb submitted these chapters to Charles C. Thomas Publishers in 1947. These were sent to Henry Nissen to review and he sent Hebb comments on each chapter.

10. Harvard and McGill: 1947- 49

Edwin G. Boring, the Chairman of the Psychology Department at Harvard, invited Hebb to teach there during the 1947 summer session. One of the classes was a graduate seminar for which Hebb used mimeographed copies of his new manuscript. One of the students in this class was Mark Rosenzweig, who wrote:

> "I took a graduate seminar with Donald O. Hebb at Harvard in the summer of 1947 where the text was a mimeographed version of Hebb's influential book *The Organization of Behavior* which appeared in print in 1949. (I wish I had had the foresight to save that 1947 version.) Hebb's creative suggestions revitalized theorizing and research on learning and memory, and I benefitted directly from them and from further contacts with him" (Rosenzweig 1998).

Hebb had been offered a position as Professor of Psychology at McGill University and he arrived in Montreal in September 1947, starting his new career at McGill with as heavy a teaching load as he had left at Queen's University five years before. Now, however, much of his teaching was with graduate students and included courses in Comparative Psychology and Physiological Psychology, in addition to supervising the research projects of graduate and honours students.

During his first year at McGill, Hebb wrote chapters 6 to 11 of *The Organization of Behavior* and sent them to Henry Nissen, Austen Riesen, Robert Blum and others for their comments. On 29 September 1948, Hebb mailed the completed version of his book to Charles C. Thomas Publishers under the title *On Thought and Behavior*. But Thomas returned Hebb's manuscript because he had a number of other books to publish and did not want to delay the publication of Hebb's book. It was turned down! With the support of letters from Frank Beach and Henry Nissen, however, John Wiley & Sons agreed to publish the manuscript, and Hebb's book, now entitled *The Organization of Behavior* was finally published in the fall of 1949.

11. What did Hebb say in *The Organization of Behavior*?

In *The Organization of Behavior*, Hebb proposed a theory for the explanation of psychological concepts such as attention, perception and learning in terms of a set of neurophysiological postulates. To do this, he proposed three key ideas. First, he argued that the synaptic connections between neurons in the cortex increased in efficiency in response to the degree of temporal contiguity in their pre- and post-synaptic activity. This concept has been termed the "Hebb synapse" and forms the basis of the "Hebbian Learning Rule" which has been used to form the basic algorithm for learning. Second, Hebb proposed that collections of neurons that tended to fire together formed a cell assembly, whose activity persisted after a sensory stimulation and formed the neural representation of that stimulation. Third, he proposed that cognitive processes such as attention and thinking occurred when sets of cell assemblies were activated in sequence, in what he termed a "phase sequence" which was the basis for the "temporally organized processes of thinking" (Hebb 1949a). Synaptic plasticity and cell assemblies have since become central tenets in behavioural and cognitive neuroscience [Spatz 1996]. The concept of synaptic plasticity suggested that synapses were not fixed, but changed depending on their stimulation, and the concept of cell assemblies showed how a number of cells could be involved in the same psychological process through their specific synaptic connections.

Hebb was critical of the Pavlovian stimulus–response model of learning, on which Hull's learning theory was based (Hull 1943), and put emphasis on Tolman's stimulus–stimulus associations (Tolman 1932). Hebb was also critical of the Gestalt theory of perceptual processes (Kohler 1929). Using his neurophysiological theory, Hebb integrated the ideas of these prominent psychological theories through common neural processes. On the basis of his theory, Hebb also reinterpreted his own previous research on Penfield's neurosurgery patients, the development of intelligence, animal models of intelligence, and emotionality in chimpanzees. The first half of the book focused on providing a neural explanation for perception and learning, and presented Hebb's concepts of synaptic plasticity, the cell assembly and phase sequence. The second half of the book demonstrated how such a neurophysiological theory could explain the development of learning capac-

ity, motivation, emotion, mental illness, and the growth and decline of intelligence. These ideas were so far ahead of their time that they were virtually untestable with the methods available and Hebb often made the point that future research was bound to prove them wrong as new information about the functioning of the nervous system became available.

12. Reviews of Hebb's book: 1949-2004

Fittingly, the published reviews of *The Organization of Behavior* were uniformly positive, even when they were critical. Kuhn (1950) stated that, "this book will probably come to be regarded as a landmark in psychological theory." Brogden (1950) wrote that, "The neural theory is admittedly gross, and probably impossible to test, but its presentation results in provocative discussion." Attneave (1950) stated "I believe *The Organization of Behavior* to be the most important contribution to psychological theory in recent years." In a lengthy review, Leeper (1950) stated "There are so many respects in which Hebb's book is so high in quality and is so delightfully written that it will have an assured status in psychology."

Of course, Hebb's book did live up to the reviewer's predictions and became one of the most important contributions to psychology in the 20th century. During the 1950's, Hebb's ideas were everywhere. Although Wertheimer (1951) criticized Hebb's views of the importance of learning in perception, Allport (1955) devoted an entire chapter (entitled "The association approach, cell assembly and phase sequence") to a discussion of Hebb's ideas on perception. In the second edition of his book on theories of learning, Hilgard (1956) added a separate section on Hebb's neuropsychological model and by 1959, Koch's monumental seven volume survey of psychology as a science had a chapter by Hebb (Hebb 1959) and refered to Hebb in every volume (Koch 1959). *The Organization of Behavior* became one of the most highly cited books in psychology and neuroscience and was required reading for many university courses in a wide variety of disciplines.

After the publication of *The Organization of Behavior*, Physiological Psychology emerged as an active field of research. The book also stimulated new ideas in other areas of psychology, biology, computer science and early childhood education. It has been translated into 11 languages and in the year 2000 the Cognitive Science Millenium Project in selecting the 100 most influential books in cognitive science in the 20th century [http://www.cogsci.umn.edu /OLD/calendar/ past_events /millennium/final.html], ranked *The Organization of Behavior* fourth (after Noam Chomsky, David Marr and Alan Turing).

The continued importance of *The Organization of Behavior* is indicated by the fact that at the 50th anniversary of its publication, it was reviewed almost as often as when it was originally published (Martinez & Glickman 1994, Nicolelis et al. 1997, Sejnowski 1999). Since the 1966 paperback reissue of *The Organization of Behavior* was out of print, Peter Milner and I had it republished in 2002 and this reissue has also been reviewed (Tees 2003). Hebb's ideas of synaptic plasticity and cell assemblies have become

fundamental concepts in psychology and neuroscience (Spatz 1996, Milner 2003, Kolb 2003, Sejnowski 2003, Hinton 2003) and the impact of Hebb's book on psychological theory has been compared with that of Darwin's *Origin of Species* on biological theory (Adams 1998). Posner & Rothbart (2004) argue that Hebb's ideas provide the basis for an integration of the disparate sub-fields of psychology. We have examined the origins of *The Organization of Behavior* (Brown & Milner 2003) and Cooper (2005) provides a history and commentary on the Hebb synapse and learning rule.

13. Hebb's evaluation of his own book

When Hebb was asked to discuss the development of his theory and its impact on psychology, he responded that he attempted to "deal with set and attention and perceptual generalization and learning in one theoretical framework, not have one approach for thinking, another for learning, and a third for perception -- the position in which the members of the Gestalt group found themselves" (Hebb 1959). Hebb continued to state that:

> "My theory is the only one that attempts this, and in my opinion, to be quite frank, is consequently the only realistic attempt to deal theoretically with the problems of behavior. Skinner of course has avoided theory; Tolman and Guthrie have proposed approaches to the problem of constructing a theory, but both have remained, essentially, programmatic. Hull's is the only real alternative to mine; and the course of development of his ideas, from 1937 to 1951, has shown a narrowing of the range of phenomena dealt with, an increasingly clear set of difficulties to be encountered even in the narrow range with which his theory does deal, and an increasing concern with minor modifications of postulates as defensive measures to meet the attacks of critics. ..... Mine, in short, is the only attempt to deal with the thought process and perception in the framework of a theory of learning. It has serious defects, but no real competitor. This fact I see as the major "evidence for the system", together with the body of research that it has, directly or indirectly, stimulated" (Hebb 1959).

14. Hebb as a teacher

Hebb had a remarkable influence on the training of psychology students at McGill. Not only did he develop a graduate program that attracted very high quality students, he also taught a very popular introductory class and wrote a textbook of psychology (Hebb 1958). Hebb also taught a graduate seminar, which was attended by all psychology graduate students and is now legendary. Hebb was involved in the 1958 Colorado conference on the teaching of psychology (Garner et al 1959) and he carried his radical ideas about teaching (Hebb 1930) to the training of graduate students.

Hebb's ideas on the training of research students (Hebb 1966) were that: (1) You can't train people to do research in courses; it is learned by apprenticeship in a research setting. (2) Graduate student research capacity and promise cannot be evaluated by examinations, but by involving the student

in research and then making an intuitive or clinical judgment of their promise. (3) Students should be given the opportunity to experience research as soon as possible, and as early as their third or fourth-year as honors students, so that they can be evaluated as thinkers and doers, not as memorizers. (4) A decision should be made on whether or not to accept a student into the PhD program after the first year, and a weak student should not be kept on, because this results in mediocre graduates. (5) You can train a student to write provided that you work closely with the student at all stages of the writing. Writing should be a main concern of the director of research. It is not subsidiary, not ancillary, not really distinguishable from the rest of the research experience. Hebb was very interested in training students to write (Hebb & Bindra 1952) and would require them to rewrite drafts of their papers many times. Hebb defined psychology as a biological science and stated that it should be studied by objective methods, rather than by introspection, humanistic or subjective methods that are more suited to literature and the arts. Hebb's focus on the biological bases of behaviour and his methods for training students turned McGill into the foremost centre for physiological psychology (now behavioural neuroscience) in the world.

15. Hebb's students and their research: 1947 - 1954

The success of Hebb's educational methods are reflected in the success of his students, including Bernard Hymovitch, Donald Forgays, Mortimer Mishkin, Brenda Milner, Peter Milner, Ronald Melzack, Seth Sharpless, Woodburn Heron, Helen Mahut, Gordon Mogenson, Case Vanderwolf and legions of others who attended his introductory psychology class and graduate seminar and were motivated to pursue biological psychology as a career. Hebb used the theories that he had developed in *The Organization of Behavior* to direct the research of his students. Often his students and colleagues repeated and extended his old experiments in light of his new theory. Since Hebb was not a co-author on any of these papers, to understand how Hebb's research was influenced by his theory, one must read the publications of his students and colleagues. For example, Rabinovitch & Rosvold (1951) developed a standardized procedure for the Hebb-Williams maze and tested rats with cortical damage and rats reared in a "free environment". Other students used the Hebb-Williams maze to test the effects of electroconvulsive shocks (Rishikof & Rosvold 1953), environmental experience and lesions (Smith 1959), thalamic stimulation (Mahut 1962), the effects of blindness and early rearing experience (Hymovitch 1952), and the effects of environmental enrichment on learning and memory (Forgays & Forgays 1952).

Beach & Jaynes (1954) reviewed the literature on the effects of early experience on behaviour of animals and stated that: "A leader in this field is Hebb, whose *The Organization of Behavior* (1949) has been directly or indirectly responsible for a number of experiments reported in psychological journals during the last two or three years." Hebb's work stimulated research on the effects of early experience on problem solving, neuroanatomy and

neurochemistry (Hunt 1979), and his ideas helped to facilitate the development of head start programmes using environmental enrichment for deprived children (Campbell et al. 1994).

Hebb did not work with patients after he left the MNI in 1939, but he did collaborate with Penfield through his students and colleagues, who often repeated studies on the effects of lesions on intelligence that Hebb began with Penfield. Rosvold & Mishkin (1950) looked at the effects of prefrontal lobotomy on intelligence as Hebb (1939a) had done, Forgays (1952) looked at the development of cognitive dysfunction after surgery and Milner (1954) investigated the intellectual function of the temporal lobes as Hebb (1939b) had done. This research led to the groundbreaking work on patient HM, which revolutionized the study of the neural basis of memory (Scoville & Milner 1957).

Hebb also continued the studies of fear and emotionality that he had started at the Yerkes Primate Laboratories, but instead of chimpanzees, he now used purebred Scottish terriers. The dogs were first tested in studies of the effects of early rearing experience on learning as Hebb had done with rats reared at home (Thompson & Heron 1954), and then in studies of emotional behaviour (Clarke et al. 1951, Mahut 1958, Melzack 1952, 1954), and the development of social behaviour (Melzack & Thompson 1956).

During the 1950's, work from Hebb's laboratory was often reported in the Montreal newspapers. For example, the work of Olds & Milner (1954) on electrical stimulation of brain reward pathways was reported on the front page of the Montreal Gazette on 12 March 1954, under the headline "McGill opens vast new research field with brain 'pleasure area' discovery". The work on sensory deprivation (Bexton et al. 1954) was reported in the Montreal Gazette of 14 January 1954 under the headline "See, hear, feel nothing research shows bored brain acts queerly: Isolation tests at McGill pay human guinea pigs $20 a day — but few can take it". The same research was treated more harshly in the New York Times of 15 April 1956, which linked Hebb's sensory deprivation experiments at McGill to brainwashing. The Montreal Gazette of 26 April 1956 ran a front page headline "Brainwashing defense found" and a second article entitled "McGill discovery will benefit military", which explained how the Defense Research Board of Canada had contracted the experiments on sensory deprivation to study "so-called brainwashing... used by opponents of western powers". This was at the time of the Korean War (1950-53), and the introduction of the term "brainwashing" in Edward Hunter's book *Brainwashing in Red China* (1951) led to the fear of brainwashing of captured soldiers. Although aspects of Hebb's sensory deprivation experiments were classified as secret, most of the results have been published, including a summary in Scientific American (Heron 1957). This work is still controversial today (McCoy 2006).

Hebb's studies of sensory deprivation also started an entire field of research and, in an introduction to a symposium which summarized the research on sensory deprivation stimulated by Hebb's ideas, Cobb (1961) states that: "When Hebb had the ingenious idea of studying perception in

human beings by means of sensory deprivation and, especially, when he courageously acted on the idea and performed his experiments, he made a great step forward. It is only seven years since he published his first paper on this subject, but one has only to look at the content of this symposium to see how quickly and fruitfully the work was taken up by others."

16. Hebb's writings following *The Organization of Behavior*

With the completion of *The Organization of Behavior*, Hebb became one of the major theorists in the field of Physiological Psychology. He was chosen to review the field of Animal and Physiological Psychology for the first Annual Review of Psychology (Hebb 1950) and, in a paper on "The role of neurological ideas in psychology", Hebb (1951) compared his theory of behaviour to those of Tolman, Krech, Hull and the Gestaltists and presented evidence for the relevance of his neurological approach to the theory of personality. Hebb's presentation at the Association for the Study of Animal Behaviour (ASAB) meeting in London, England, focussed on the problem of separating genetic and environmental components of behaviour. In this paper, he stated that asking what percentage of behaviour is due to heredity and what percentage due to environment "...is exactly like asking how much of the area of a field is due to its length, how much due to its width" (Hebb 1953a). In this paper, he also criticized the ethologists for attempting to study innate behaviour before studying learning as he felt that all forms of behaviour involve some type of learning.

In his presidential address to the Canadian Psychological Association (CPA), Hebb (1953b) argued that human thought was the central problem for psychology. He further argued that the existence of thought was denied by stimulus-response behaviorists such as Thorndike, and not explained by the Gestalt theorists. Hebb then discussed how his cell assembly model could account for the concept of thought. Hebb & Thompson (1954) discussed Hebb's research on chimpanzee emotional behaviour and his work on the importance of environmental experience in the development of behaviour and suggested that emotionality and psychopathology result from breakdowns in cell assemblies.

In his presidential address to Division 3 of the American Psychological Association (APA), Hebb (1955a) discussed the concept of motivation in terms of the CNS (Conceptual Nervous System). Hebb wrote this paper in response to B.F. Skinner who had stated that "the letters CNS be regarded as representing not the Central Nervous System, but the Conceptual Nervous System. Many theorists point out that they are not talking about the nervous system as an actual structure undergoing physiological or biochemical changes but only as a system with a certain dynamic output" (Skinner 1950). What Hebb showed was that conceptualizing psychological problems in physiological terms led to research on the neural basis of behaviour, as shown by the work of Moruzzi and Magoun on the brain stem arousal system and the results of Olds and Milner's studies of reward by

electrical brain stimulation. He also presented the idea of an inverted U shaped curve to describe the optimal arousal of behaviour.

In his presentation to the American Psychiatric Foundation, Hebb (1955b) again discussed the importance of environmental stimulation during development, relating it to levels of adjustment at maturity. In particular, Hebb pointed out that "a short period of deprivation of normal sensory input produces personality changes and a clear loss of capacity to solve problems" (Hebb 1955b). He used examples from his research on dogs and rats and the effects of sensory deprivation in humans to illustrate this point. Thus, in the years after the publication of *The Organization of Behavior*, Hebb was able to show how his theories could be applied to the study of the full range of psychological problems.

17. Hebb's involvement in the promotion of psychology

Hebb's promotion of research in Physiological Psychology at McGill, in combination with the research at the MNI made Montreal a world centre for brain research and attracted two major conferences in the early 1950's. The first was the Brain Mechanisms and Consciousness Symposium, which was held in Ste-Marguerite, Quebec, in August 1953 (Delafresnaye 1954). This meeting brought the top neuroscientists from all over the world to Quebec. These included H.W. Magoun, who presented a review of the ascending reticular activating system and wakefulness and G. Moruzzi, who reported on the physiological properties of the brain stem reticular activating system. Walle Nauta, W.R. Hess, Mary Brazier, and E.D. Adrian (later Lord Adrian), all gave presentations, as did Wilder Penfield, W. Grey Walter and Herbert Jasper. Hebb spoke on the problem of consciousness and introspection in which he discussed his experiments on sensory deprivation. Lashley spoke on dynamic processes in perception and Lawrence Kubie spoke on psychiatric and psychoanalytic considerations of the problem of consciousness.

The second meeting, the 14th International Congress of Psychology, was held in Montreal in June 1954. It was presided over by Edward C. Tolman, the President of the APA and Edward A. Bott, the President of the CPA (Rosenzweig et al. 2000). Hebb was the Chairman of the Local Arrangements Committee, along with other faculty members from McGill and the University of Montreal (Proceedings 1954). Over 1000 psychologists from 31 countries, including Russia, attended this meeting, which had plenary talks by Jean Piaget, Wilder Penfield and Edward C. Tolman. The delegation of six Russians included E.N. Sokolov, A.N. Leontiev and E.A. Asratyan.

After Hebb's book was published, he was invited to give lectures at many scientific meetings and at universities throughout North America and Europe. Hebb's first major lecture was the James Arthur Lecture entitled "The evolution of thought and emotion", which he gave at the American Museum of Natural History in New York in 1948. In 1950 and 1951, he gave lectures in Chicago, Michigan and Yale. He also had a lecture tour of England in April and May of 1952; it was his first trip to Europe. During this trip, he

gave three lectures at the University of London, one at Oxford and one at the Maudsley Hospital as well as an Association for the Study of Animal Behaviour Lecture on heredity and environment (Hebb 1953a). Hebb also gave the Hughlings Jackson Lecture at the Montreal Neurological Institute in 1958 and the Claude Bernard Lecture at the Universite de Montreal in 1966. Notes for many more lectures abound in his collected materials.

Hebb also became a spokesman for psychology as a science, both within Canada and internationally. He was elected the president of the CPA in 1953 and promoted the publication of high quality research in the Canadian Journal of Psychology, where many of his students published their papers. Hebb also worked tirelessly to increase support for research in psychology. He served on the Human Resources Research Advisory Committee of the Defense Research Board of Canada from 1951 to 1953, and lobbied the National Research Council to have a section for research in Experimental Psychology, which he chaired from 1956-62. He also served on the Board of Scientific Counselors of the National Institute for Mental Health from 1965 to 1969.

Hebb became a member of the APA in 1936 and attended most of the APA meetings between 1940 and 1973. He was also involved in administration of the APA as President of Division 3 (Experimental Psychology) in 1953 (Hebb 1955a) and President of the APA in 1959, the first non-American to be elected (Hebb 1960). In 1961, Hebb was awarded an APA Distinguished Contribution Award (Hebb 1963) and in 1973, he was invited to address the APA on "What Psychology is About" (Hebb 1973).

18. Hebb's awards

Throughout his career, Hebb received many honours, including the Warren Medal from the Society of Experimental Psychologists (1958), the distinguished scientific contribution award from the APA (1961), and an award from the Association for Research in Nervous Mental Disorders (1962). He was awarded the Claude Bernard Medal from the University of Montreal (1966), the Gold Medal from the APA (1974), the Society for Research in Child Development Distinguished Scientific Contribution Award (1979) and the CPA Distinguished Scientific Contribution Award (1980). He was elected a Fellow of the Royal Society of Canada (1959) and the Royal Society of London (1966). He was given honorary doctorates by 15 Universities and was nominated for the Nobel Prize in Physiology and Medicine in 1965. These awards, from so many different societies, give some indication of the wide impact of his work.

19. Hebb retires to Nova Scotia

Hebb was the chairman of the Psychology Department at McGill from 1948 to 1958 and the Vice-Dean of Biological Sciences from 1964 to 1966. He was then elected Chancellor of McGill University from 1970 to 1974. As Chancellor, he presided over many university events and gave a number of public lectures, such as his lecture on the importance of a university education (Hebb 1971).

In 1977, Hebb retired to Marriot's Cove, Nova Scotia, only a few miles from Chester, his birthplace. He became a Professor Emeritus at Dalhousie University and commuted to Halifax once a week for lunch with colleagues, including Graham Goddard, Lynn Nadel, Ray Klein, John Fentress and their students, who included Carol Barnes, Bruce McNaughton and Rob Douglas. Hebb always enjoyed sailing and went out in his boat, "The Raven" whenever he could. While he was "retired", he wrote his third book, *Essay on Mind* (Hebb 1980a), a summary of his ideas on the biological basis of mind. He also gave a number of interviews to Psychology Today, wrote an introspective account of aging (Hebb 1978) and completed his autobiography (Hebb 1980b, c).

20. The legacy of Hebb's work

Hebb died on 20 August 1985, following complications from surgery. Numerous obituaries were published which described his legacy to every area of psychology and neuroscience (Harnad 1985, Fentress 1987, Klein 1989). Modern neuropsychology is indebted to Hebb's work with Penfield. The study of environmental effects on development derives from Hebb's pet rats reared at home. Computer models of the brain are based on Hebb's ideas of the synapse and cell assembly. Long-term potentiation (Bliss & Lomo 1973) is the experimental analysis of Hebbian synaptic plasticity. The work of Hubel and Wiesel on neural plasticity of sensory system development (Weisel & Hubel 1965) derives from the first five chapters of *The Organization of Behavior* (Stent 1973). The field of computational neuroscience is based largely on Hebb's ideas (Sommer & Wennekers 2003). His emphasis on the effects that the timing of neural impulses have on brain function is in keeping with the discovery of spike-time-dependent synaptic plasticity (Bi & Poo 2001, Sejnowski 1999). In addition, studies of the neural bases of emotion, motivation, reward, and pain pathways derive from Hebb's ideas and the research of his students. Although a 2002 study ranked Hebb as only the 19th most eminent psychologist of the 20th Century (Haggbloom et al. 2002), a greater awareness of what we owe to Hebb should increase this ranking substantially.

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REFERENCES

Adams P (1998) Hebb and Darwin. J Theor Biol 195:419–438

Allport FH (1955) Theories of perception and the concept of structure. John Wiley and Sons, New York

Attneave F (1950) The organization of behavior: a neuropsychological theory. Amer J Psych 63:633-635

Babkin BP (1942) How I came to Dalhousie. J Mt Sinai Hospital 9:168-175

Beach FA, Jaynes J (1954) Effects of early experience upon the behavior of animals. Psych Bull 51:239-263

Bell R (1977) Wilder Penfield: his legacy to neurology. Can Med Assn J 18:1365 -1377

Bexton WH, Heron W, Scott RH (1954) Effects of decreased variation in the sensory environment. Can J Psychol 8:70-76

Bi G, Poo M (2001) Synaptic modification by correlated activity: Hebb's postulate revisited. Annu Rev Neurosci 24:139-166

Bliss TV, Lomo T (1973) Long-lasting potentiation of synaptic transmission in the dentate area of the anaesthetized rabbit following stimulation of the perforant path. J Physiol 232:331-356

Brogden WJ (1950) Organization of behavior. Scientific Monthly, 17:283-284

Brooks CM, Eccles JC (1947) An electrical hypothesis of central inhibition. Nature 159:760-764

Brown RE, Milner PM (2003) The legacy of Donald O. Hebb: more than the Hebb synapse. Nature Rev Neurosci 4:1013-1019

Campbell FA, Ramey CT (1994) Effects of early intervention on intellectual and academic achievement: a follow-up study of children from low-income families. Child Dev 65:684-98

Clarke RS, Heron W, Fetherstonhaugh ML, Forgays DG, Hebb DO (1951) Individual differences in dogs: preliminary report on the effects of early experience. Can J Psych 5:150-156

Cobb S (1961) Foreword. In: Solomon P, Kubzansky PE, Leidermann PH, Mendelson JH, Trumbell R, Wexler D (eds) Sensory deprivation. Harvard University Press, Cambridge, Mass

Cooper SJ (2005) Donald O. Hebb's synapse and learning rule: a history and commentary. Neurosci Biobehav Rev 28:851-874

Delafresnaye JF (ed) (1954) Brain mechanisms and consciousness. Charles C. Thomas Publishers, Springfield, Illinois

Dewsbury DA (2002) The Chicago five: a family group of integrative psychobiologists. History Psychol 5:16–37

Eccles J (1976) From electrical to chemical transmission in the central nervous system. Notes & Records Royal Soc Lond 30:219-230

Eccles JC (1982) The synapse: from electrical to chemical transmission. Ann Rev Neurosci 5:325-339

Eccles JC, Fatt P, Koketsu K (1954) Cholinergic and inhibitory synapses in a pathway from motor-axon collaterals to motoneurones. J Physiol (Lond) 126:524-562

Feindel W (1992) Brain physiology at the Montreal Neurological Institute: some historical thoughts. J Clin Neurophysiol 9:176-194

Fentress JC (1987) D.O. Hebb and the developmental organization of behavior. Dev Psychobiol 20:103–109

Ferguson GA (1993) Psychology in Canada: 1939-45. Can Psych 33:697-705
Forgays DG (1952) Reversible disturbances of function in man following cortical insult. J Comp Physiol Psych 45:209-215
Forgays DG, Forgays JW (1952) The nature of the effect of free-environmental experience in the rat. J Comp Physiol Psych 45:322-328
Garner WR, Hunt HF, Taylor DW (1959) Education for research in psychology. Amer Psych 14:167-179
Haggbloom SJ, Warnick R, Warnick JE (2002) The 100 most eminent psychologists of the 20th century. Rev Gen Psych 6:139–152
Harnad S (1985) D.O. Hebb: father of cognitive psychobiology: 1904–1985. Behav Brain Sci 8: page765
Hebb DO (1925) 25 class history. Dalhousie Gazette, 25-29
Hebb DO (1930) Elementary school methods. Teacher's Magazine 12:23–26
Hebb DO (1932) Conditioned and unconditioned reflexes and inhibition. MA thesis, McGill University, Montreal, Quebec
Hebb DO (1934) The interpretation of experimental data on neural action. Unpublished manuscript
Hebb DO (1936) The innate organization of visual perception in the rat. PhD thesis, Harvard University, Boston, Mass
Hebb DO (1937) The innate organization of visual activity: I. Perception of figures by rats reared in total darkness. J Genetic Psych 51:101–126
Hebb DO (1938) Studies of the organization of behavior. I. Behavior of the rat in a field orientation. J Comp Psychol 25:333–353
Hebb DO (1939a) Intelligence in man after large removals of cerebral tissue: report of four left frontal lobe cases. J Gen Psychol 21:73–87
Hebb DO (1939b) Intelligence in man after large removals of cerebral tissue: defects following right temporal lobotomy. J Gen Psychol 21: 437–446
Hebb DO (1941) Higher level difficulty in verbal test material. Bull Can Psych Assn 1:29
Hebb DO (1942) The effects of early and late brain injury upon test scores, and the nature of normal adult intelligence. Proc Amer Phil Soc 85:275–292
Hebb DO (1945a) Man's frontal lobes: a critical review. Arch Neurol Psychiatry 54:10–24
Hebb DO (1945b) The forms and conditions of chimpanzee anger. Bull Can Psych Assn 5:32-35
Hebb DO (1945c) Precis: The structure of a set of neuropsychological speculations. Unpublished manuscript
Hebb DO (1946) On the nature of fear. Psych Rev 53:259-276
Hebb DO (1947a) Spontaneous neurosis in chimpanzees: theoretical relations with clinical and experimental phenomena. Psychosom Med 9:3-19
Hebb DO (1947b) The effects of early experience on problem solving at maturity. Amer Psych 2:306–307
Hebb DO (1949a) The organization of behavior: a neuropsychological theory. Wiley, New York [Reprinted 2002 by Lawrence Erlbaum Associates, Mahwah, New Jersey]
Hebb DO (1949b) Temperament in chimpanzees: I. Method of analysis. J Comp Physiol Psych 42:192-206
Hebb DO (1950) Animal and physiological psychology. Ann Rev Psych 1:173-188
Hebb DO (1951) The role of neurological ideas in psychology. J Personality 20:39-55

Hebb DO (1953a) Heredity and environment in mammalian behaviour. Br J Anim Behav 1:43-47
Hebb DO (1953b) On human thought. Can J Psych 7:99-110
Hebb DO (1954) The problem of consciousness and introspection. In: Delafresnaye JF (ed) Brain mechanisms of consciousness. Charles C. Thomas Publishers, Springfield, Illinois, p 402-421
Hebb DO (1955a) Drives and the C.N.S. (conceptual nervous system). Psych Rev 62:243-254
Hebb DO (1955b) The mammal and his environment. Amer J Psychiat 111:826-831
Hebb DO (1958) A textbook of psychology. Saunders, Philadelphia
Hebb DO (1959) A neuropsychological theory. In: Koch S (ed) Psychology: a study of a science, Vol 1. McGraw-Hill, New York, p 622-643
Hebb DO (1960) The American revolution. Amer Psychol 15:735-745
Hebb DO (1963) The semiautonomous process: its nature and nurture. Amer Psychol 18:16-27
Hebb DO (1966) Education for research. Can Feder News 8:53-57
Hebb DO (1971) The nature of a university education. McGill J Educ 6:5-14
Hebb DO (1974) What psychology is about. Amer Psychol 29:71–79
Hebb DO (1978) On watching myself get old. Psych Today 12(6):15-23
Hebb DO (1980a) Essay on mind. L Erlbaum Associates, Hillsdale, NJ
Hebb DO (1980b) D.O. Hebb. In: Lindzey G (ed.). A history of psychology in autobiography, Vol VII. WH Freeman, San Francisco, p 273-309
Hebb DO (1980c) An account of my life written for my daughters and grandchildren. Unpublished manuscript
Hebb DO (1980d) This is how it was: fifty years in psychology, forty years a psychologist. Presentation at the Canadian Psychology Association Meeting, Halifax, Nova Scotia. Unpublished
Hebb DO, Bindra D (1952) Scientific writing and the general problem of communication. Amer Psychol 7:569-573
Hebb DO, Foord EN (1945) Errors of visual recognition and the nature of the trace. J Exp Psych 35:335-348
Hebb DO, Morton NW (1943) The McGill adult comprehension examination: verbal situation and picture anomaly series. J Educ Psych 34:16–25
Hebb DO, Morton NW (1944) Note on the measurement of adult intelligence. J Gen Psychol 30:217–223
Hebb DO, Penfield W (1940) Human behavior after extensive bilateral removal from the frontal lobes. Arch Neurol Psychiatry 42:421– 438
Hebb DO, Thompson WR (1954) The social significance of animal studies. In: Lindzey G (ed) Handbook of social psychology, Vol 1. Addison-Wesley, Cambridge Mass, p 532-561
Hebb DO, Williams KA (1946) A method of rating animal intelligence. J Gen Psychol 34:59–65
Heron W (1957) The pathology of boredom. Sci Amer 196:52–56
Hilgard ER (1956) Theories of learning, 2nd edn. Appleton-Century-Crofts New York
Hilgard ER, Marquis DG (1940) Conditioning and learning. Appleton-Century-Crofts, New York
Hinton G (2003) The ups and downs of Hebb synapses. Can Psychol 44:10-13
Hull CL (1943) Principles of behavior: an introduction to behavior theory. Appleton-Century, New York

Hunt J M (1979) Psychological development: early experience. Ann Rev Psych 30:103-143

Hunter E (1951) Brainwashing in red China: the calculated destruction of men's minds. Vanguard Press, New York

Hymovitch B (1952) The effects of experimental variations on problem solving in the rat. J Comp Physiol Psychol 45:313-321

Kingsbury FA (1946) A history of the department of psychology at the University of Chicago. Psych Bull 43:259-271

Klein RM (1989) The Hebb legacy. Can J Exp Psych 53:1–3

Koch S 1959) Psychology: a study of a science, 7 volumes. McGraw-Hill, New York

Kohler W (1929) Gestalt psychology. H Liveright, New York

Kolb B (2003) The impact of the Hebbian learning rule on research in behavioural neuroscience. Can Psychol 44:14-16

Krech D, Rosenzweig MR, Bennett EL (1962) Relations between chemistry and problem-solving among rats raised in enriched and impoverished environments. J Comp Physiol Psychol 55:801-807

Kuhn MH (1950) Hebb, D. O. Organization of behavior: a neuropsychological theory. Ann Amer Acad Pol Soc Sci 217:216-217

Lashley KS (1929) Brain mechanisms and intelligence: a quantitative study of injuries to the brain. University of Chicago Press, Chicago [Reprinted 1963, Dover Press, New York]

Lashley KS (1930) Basic neural mechanisms in behavior. Psych Rev 37:1-24

Leeper R (1950) The organization of behavior: a neuropsychological theory (review). J Abnorm Soc Psychol 45:768-775

Lorente de No R (1938) Synaptic stimulation of motoneurons as a local process. J Neurophysiol 1:195-206

MacLeod EJ (1990) Petticoat doctors: the first forty years of women in medicine at Dalhousie University. Pottersfield Press, Lawrencetown, NS

Mahut H (1958) Breed differences in the dog's emotional behaviour. Can J Psych 12:35-44

Mahut H (1962) Effects of subcortical electrical stimulation on learning in the rat. J Comp Physiol Psych 55:472-477

Martinez JL Jr, Glickman SE (1994) Hebb revisited: perception, plasticity, and the Hebb synapse. Contemp Psychol 39:1018-1020

McBride AF, Hebb DO (1948) Behavior of the captive bottle-nose dolphin, *Tursiops truncatus*. J Comp Physiol Psych 41:111-123

McCoy AW (2006) A question of torture: CIA interrogation, from the cold war to the war on terror. Metropolitan Books, New York

Melzack R (1952) Irrational fears in the dog. Can J Psych 6:141-147

Melzack R (1954) The genesis of emotional behavior: an experimental study of the dog. J Comp Physiol Psych 47:166-168

Melzack R, Thompson WR (1956) Effects of early experience on social behaviour. Can J Psych 10:82-90

Milner B (1954) Intellectual function of the temporal lobes. Psych Bull 51:42-62

Milner PM (1957) The cell assembly: Mark II. Psych Rev 64:242-252

Milner PM (2003) A brief history of the Hebbian learning rule. Can Psychol 44:5-9

Morgan CT (1943) Physiological psychology. McGraw-Hill Book Company Inc, New York

Nicolelis MA, Fanselow EE, Ghazanfar AA (1997) Hebb's dream: the resurgence of cell assemblies. Neuron 19:219-221

Olding HH Jr (1976) Olding and allied families and descendents of Nicolas Purdue Olding of Merigomish, Nova Scotia. Privately published by Herbert Harris Olding, Jr, East Hartford, CT 06108

Olds J, Milner P (1954) Positive reinforcement produced by electrical stimulation of septal area and other regions of rat brain. J Comp Physiol Psychol 47:419-427

Patterson FH (1955) John Patterson the founder of Pictou Town. Truro Publishing and Printing Co, Truro, Nova Scotia. See also: Patterson G (1877/1972) A history of the county of Pictou, Nova Scotia. Dawson Brothers, Montreal, Quebec

Posner MI, Rothbart MK (2004) Hebb's neural networks support the intergration of psychological science. Can Psychol 45:265-278

Proceedings of the Fourteenth International Congress of Psychology, Montreal, June 1954. North Holland Publishing Company, Amsterdam

Queen's University (1940-41) Course calendar. Departmental prescriptions Mental and Moral Philosophy, p 142-148

Rabinovitch MS, Rosvold HE (1951) A closed-field intelligence test for rats. Can J Psych 5:122-128

Riesen AH (1947) The development of visual perception in man and chimpanzee. Science 106:107-108

Rishikof JR, Rosvold HE (1953) Effects of electroconvulsive shocks on the performance of the rat in the closed-field test. Can J Psych 7:29-33

Rosenzweig MR (1998) Some historical background of topics in this conference. Neurobiol Learn Memory 70:3-13

Rosenzweig MR, Holtzman WH, Sabourin M, Belanger D (2000) History of the International Union of Psychological Science. Psychology Press, Hove, UK

Rosvold HE, Mishkin M (1950) Evaluation of the effects of prefrontal lobotomy on intelligence. Can J Psych 3:122-127

Scoville WB, Milner B (1957) Loss of recent memory after bilateral hippocampal lesions. J Neurol Neurosurg Psychiatry 220:11–21

Sejnowski TJ (1999) The book of Hebb. Neuron 24:773–776

Sejnowski TJ (2003) The once and future Hebb synapse. Can Psychol 44:17-20

Shore DI, Stanford L, MacInnes JW, Klein RM, Brown RE (2001) Of mice and men: virtual Hebb-Williams mazes permit comparison of spatial learning across species. Cognitive, Affective & Behav Neurosci 1:83-89

Silver A (1993) Catherine Olding Hebb (1911-1978). In: Bindman L, Brading A, Tansey T (eds) Women physiologists: an anniversary celebration of their contributions to British physiology. Portland Press, London, p 123-127

Skinner BF (1950) Are theories of learning necessary? Psych Rev 57:193-216

Smith CJ (1959) Mass action and early environment in the rat. J Comp Physiol Psych 52:154-156

Sommer FT, Wennekers T (2003) Models of distributed associative memory networks in the brain. Theory in Biosciences 122:55-69

Spatz HC (1996) Hebb's concept of synaptic plasticity and neuronal cell assemblies. Behav Brain Res 78:3–7

Stent GS (1973) A physiological mechanism for Hebb's postulate of learning. Proc Nat Acad Sci USA 70:997-1001

Teal SW (1994) The Hebb mill affair: the history of the Hebb family (1682-1994). Privately published by Scott Winston Teal, Lower Sackville, Nova Scotia

Tees RC (2003) The organization of behavior: a neuropsychological theory. Can Psychol 4:74-76

Thompson WR, Heron W (1954) The effects of restricting early experience on the problem-solving capacity of dogs. Can J Psych 8:17-31

Tolman EC (1932) Purposive behavior in animals and men. The Century Co, New York

van Praag H, Kempermann G, Gage FH (2000) Neural consequences of environmental enrichment. Nat Rev Neurosci 1:191-198.

von Senden M (1932) Raum- und Gestaltauffassung bei Operierten Blindgebornen von und nach der Operation. JA Barth, Liepzig

von Senden M (1960) Space and sight: the perception of space and shape in the congenitally blind before and after operation. Methuen & Co, London (English translation by Peter Heath, with appendices by AH Riesen, GJ Warnock and JZ Young, and a select bibliography of books and papers citing this work)

Wiesel TN, Hubel DH (1965) Comparison of the effects of unilateral and bilateral eye closure on cortical unit responses in the kitten. J Neurophysiol 28:1029-1040

Wertheimer M (1951) Hebb and Senden on the role of learning in perception. Amer J Psych 64:133-137.

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DEEP-WATER CORALS IN ATLANTIC CANADA: A REVIEW OF DFO RESEARCH (2001-2003)

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Deep-water corals occur in Atlantic Canada at water depths in the general range of 200-1500 m. Prior to 2000, most knowledge of deep-water corals was anecdotal and based primarily on fishing bycatch information. During 2001-2003, in collaboration with university colleagues, the Department of Fisheries and Oceans (DFO) at the Bedford Institute of Oceanography investigated the distribution, abundance, habitat and biology of deep-water corals and their associated fauna under funding provided in part by the Environmental Studies Research Fund. Data were gathered from DFO groundfish surveys, the Fisheries Observer Program, interviews with fishers and dedicated research cruises with specialized imaging and sampling equipment. Nineteen coral taxa were collected or observed alive in their natural habitat; 6 Alcyonacea (soft corals), 7 Gorgonacea (horny corals), 5 Scleractinia (stony corals), and 1 Antipatharia (black corals). The results confirmed earlier observations that the Northeast Channel, the Gully and the Stone Fence are prime coral habitats. The first documented *Lophelia* reef complex in Atlantic Canada was found near the Stone Fence in the mouth of the Laurentian Channel. The distribution of deep-water corals is patchy and influenced by several environmental factors including substrate, temperature, salinity and currents. The average height of *Primnoa* and *Paragorgia* colonies was 30 and 57 cm. At their estimated growth rates of 1.7 and 1 cm /year, respectively, the largest *Primnoa* colony observed was about 61 years old while the largest *Paragorgia* colony was about 180 years old. Deep-water corals host a rich associated fauna, and 114 taxa have been identified to date on *Paragorgia* and *Primnoa* in Atlantic Canada. Numerous species of fish have also been observed associated with deep-water corals, the most abundant being redfish. Damage from fishing gear was found to be most extensive at the *Lophelia* reef complex at the Stone Fence. A lower level of fishing damage was observed in the Northeast Channel while few indications of damage were observed in the Gully. The results of this program have been used by DFO to create coral conservation areas at the Northeast Channel (424 km^2) and Stone Fence (15 km^2) that are closed to bottom-fishing activities. Substantial knowledge gaps still exist, in particular quantitative information of deep-water corals at depths below 500 m, and these are being addressed by continuing collaborative research by DFO and universities.

Les coraux abyssaux sont communs au Canada atlantique à des profondeurs allant de 200 à 1 500 m. Avant 2000, la plupart des données sur les coraux abyssaux étaient de nature anecdotique et fondées principalement sur des données sur les prises accessoires lors d'activités de pêche. De 2001 à 2003, des chercheurs de l'Institut océanographique de Bedford du ministère des Pêches et des Océans (MPO), en collaboration avec des collègues du milieu universitaire, ont étudié la répartition, l'abondance, l'habitat et la biologie des coraux abyssaux et des espèces qui leurs sont associées dans le cadre d'un projet financé en partie par le Fonds pour l'étude de l'environnement. Les chercheurs ont recueilli des données obtenues dans le cadre de relevés du poisson

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de fond menés par le MPO, du Programme des observateurs des pêches, d'entrevues avec des pêcheurs et de croisières de recherche à bord de bateaux munis d'un équipement spécialisé d'échantillonnage et d'imagerie. Au total, 19 taxons de coraux ont été recueillis ou observés vivants dans leur habitat naturel : 6 *Alcyonacea* (coraux moux), 7 *Gorgonacea* (coraux cornés), 5 *Scleractinia* (coraux durs) et 1 *Antipatharia* (coreaux noirs). Les résultats confirment les observations antérieures selon lesquelles le chenal Nord-Est, le Goulet et le secteur de Stone Fence constituent des habitats de grande qualité pour les coraux. Le premier récif de *Lophelia pertusa* découvert au Canada atlantique est situé à proximité du secteur de Stone Fence, à l'embouchure du chenal Laurentien. La distribution des coraux abyssaux est éparse et dépend de plusieurs facteurs environnementaux, y compris le substrat, la température, la salinité et les courants. La hauteur moyenne des colonies de *Primnoa* et de *Paragorgia* observées était respectivement de 30 et de 57 cm. D'après les taux de croissance estimés à 1,7 (*Primnoa*) et 1 cm/année (*Paragorgia*), la plus grande colonie de *Primnoa* observée était âgée d'environ 61 ans, tandis que la plus grande colonie de *Paragorgia* avait environ 180 ans. Les coraux abyssaux sont les hôtes d'une riche faune associée. Jusqu'à maintenant 114 taxons différents ont été identifiés sur les colonies de *Paragorgia* et de *Primnoa* au Canada atlantique. De nombreuses espèces de poissons ont également été observées en association avec les coraux abyssaux, la plus abondante étant le sébaste. Les plus importants dommages causés par des engins de pêche ont été observés au récif de *Lophelia* dans le secteur de Stone Fence. Des dommages moins importants attribuables à la pêche ont été observés dans le chenal Nord-Est, et peu d'indices de dommages ont été signalés dans le Goulet. Le MPO a utilisé les résultats du présent projet pour créer des zones de conservation des coraux dans le chenal Nord-Est (424 km^2) et dans le secteur de Stone Fence (15 km^2) où les activités de pêche de fond sont maintenant interdites. Il existe encore des lacunes considérables dans les données, en particulier dans le cas des données quantitatives sur les coraux abyssaux à plus de 500 m de profondeur, et ces lacunes continuent d'être comblées par le biais des recherches conjointes menées par le MPO et des universités.

INTRODUCTION

Deep-water corals are found around the world and are important components of deep-water ecosystems. While their existence has been known for many years, they have received very little scientific attention compared to their shallow-water relatives, in large part because of the logistic difficulties in studying them. However, with the recent development of technologies such as ROVs and video platforms, it is now possible to study deep-water corals in their natural habitat. As a result, knowledge of deep-water corals is currently growing rapidly.

More than 700 species of deep-water corals occur world-wide (Freiwald et al. 2004). As described by Breeze et al. (1997), the term "coral" has been used to describe several different orders within the Phylum Cnidaria and the Subphylum Anthozoa. There are two classes of Anthozoans. The Hexacorallia include the true or stony corals (scleractinians), the antipatharian corals and sea anemones (actinarians) while the Octocorallia include the soft or leather corals (alcyonaceans), the horny corals (gorgonians) and the sea pens (pennatulaceans).

Most corals grow attached to stable substrate (e.g. cobbles, boulders, bedrock) while some are anchored in finer sediments and others are free-living. All corals are epibenthic and most have arborescent growth forms.

They can range in size from just a few centimetres to over 3 m. Numerous deep-water corals provide habitat structure. Certain species of stony corals can form reef complexes that can be many meters high and extend horizontally for over a kilometer. Some species of large horny corals can form dense thickets commonly known as 'forests'. Deep-water corals are adapted to live without light and at relatively low temperatures (4-13°C). They feed by capturing zooplankton and organic particles from the surrounding water. Growth rates are very low and colonies can be hundreds of years old. Biodiversity is higher in and around deep-water corals compared with adjacent areas. They provide shelter and feeding places for a wide variety of invertebrates and fish. It has also been suggested that they serve as spawning and nursery sites for some species. Additionally, the impressive ages documented for some colonies and the calcified accretions of their skeletons make them valuable for paleoclimatic studies. Deep-water corals are highly vulnerable to human activities, in particular fishing, and there is a strong international conservation movement for the protection of deep-water corals with calls for closed areas and bans on certain gear types.

Deep-water corals are common in Atlantic Canada. Early scientific reports include Verrill (1922) and Deichmann (1936). Using all available information which included the scientific literature, museum collections and bycatch reports, Breeze et al. (1997) reviewed the distribution and status of corals off Nova Scotia and reported the presence of 35 taxa, including 7 soft corals, 10 horny corals, 10 stony corals and 8 seapens. With the exception of soft corals, which are also found in shallow water, most deep-water corals in Atlantic Canada occur at depths between 200-1500 m along the edge of the continental shelf, in submarine canyons and in channels between fishing banks. Prime locations include the Northeast Channel, the Gully and the Stone Fence. Photographs of the more common deep-water coral taxa found off Nova Scotian are provided in Fig 1.

Human activities such as fishing and hydrocarbon extraction have the potential to seriously impact deep-water corals. Since our knowledge on deep-water corals and their habitats in Atlantic Canada remains sketchy, it has been necessary to collect more detailed information on their distribution, abundance and biology that can be used to make better informed management decisions regarding their protection from human activities. To this end, in 1997 the Department of Fisheries and Oceans (DFO) began to collect video and photographic information of deep-water corals on an opportunity basis at prime sites off Nova Scotia. A start was also made to capture information on deep-water corals collected as bycatch in the annual DFO groundfish trawl surveys. The results of this preliminary work were summarized in MacIsaac et al. (2001). Corals were observed at all sites surveyed and the results were in general agreement with the observations summarized by Breeze et al. (1997).

In 2001, a more formal DFO research program was established under funding from the Environmental Studies Research Funds (ESRF) and DFO. The ESRF is an oil and gas industry-funded program, administered by the

Fig 1. Photographs taken by Campod of common corals off Nova Scotia in their natural habitat.

Fig 1A. A blue, broccoli-shaped soft coral attached to a cobble. The white object is an encrusting sponge.

Fig 1B. The gorgonian *Primnoa resedaeformis*, commonly called sea corn, with soft corals and redfish seeking shelter.

Fig 1C. The gorgonian *Paragorgia arborea*, commonly called bubblegum coral, with soft corals, anemones and sponges.

Fig 1D. The gorgonian *Keratoisis ornate*, also known as bamboo coral.

Fig 1E. The reef-building stony coral *Lophelia pertusa* with a redfish seeking shelter.

Fig 1D. The free-living stony coral *Flabellum alabastrum* on sandy seabed.

National Energy Board, that supports environmental and social studies pertaining to exploration, development and production activities on Canadian frontier lands. Dr. Pål Mortensen, who had just finished his PhD on deep-water corals in Norway, was recruited as a Visiting Fellow through the National Scientific and Engineering Research Council (NSERC). In addition, Dr. Lene Buhl-Mortensen, a Norwegian specialist on deep-water benthic invertebrates, was hired through the Marine Invertebrate Diversity Initiative (MIDI). Funding was also provided to Ms. Susan Gass while she pursued her master's degree in environmental studies at Dalhousie University. This program was conducted with the assistance and collaboration of numerous government, university and industry colleagues.

During 2001-2003, a large amount of new data on deep-water corals in Atlantic Canada was collected and analyzed. Data sources included DFO groundfish trawl surveys, the Fisheries Observer Program, interviews with fishers and dedicated cruises to regions of particular interest using DFO research vessels and sampling equipment including Campod, Videograb and ROPOS. Some laboratory work with live corals was also done. This paper reviews the major results of this three-year research program. Full details can be found in the final report prepared for ESRF (Mortensen et al. 2006) and the numerous scientific papers referenced herein.

DISTRIBUTION AND ABUNDANCE

Corals were collected on four DFO groundfish trawl surveys on the Scotian Shelf, five off Newfoundland & Labrador, and two in the Davis Strait. These surveys are shelf-wide and only a limited number of the sets returned corals. In total, 57 specimens were collected representing seven taxa (Gass 2002, Gass & Willison 2005). As part of the Fisheries Observer Program, also shelf-wide, observers recorded 170 instances of corals being collected in commercial fishing gear. Six taxa were collected by four gear types (otter trawls, shrimp trawls, bottom longlines, and bottom gillnets) with longlines accounting for the greatest number of captures (Gass 2002, Gass & Willison 2005). These records indicated the presence of corals ranging all the way from Jordan Basin in the Gulf of Maine northward to Davis Strait, generally along the edge of the continental shelf. Combining the two data sets, eight coral taxa were observed and their depth ranges are summarized in Table 1. The most frequently encountered taxa were the gorgonians *Primnoa resedaeformis* and *Paragorgia arborea.* The depth range of half the taxa extended well below 500 m.

Of the 36 fishers interviewed in eastern Nova Scotia and Newfoundland & Labrador, 26 had encountered deep-water corals while fishing with otter trawls, gillnets or longlines (Gass 2002, Gass & Willison 2005). Eight taxa were identified (Table 2). With two exceptions, these were the same taxa observed in the DFO groundfish surveys and the Fisheries Observer Program (Table 1). *Acanthogorgia armata* was not recorded by the fishers, but one

fisher produced a sample of coral which turned out to be the first identified antipatharian black coral in Atlantic Canada (*Bathypathes* sp.).

Table 1 Coral taxa and their depth ranges based on data from DFO groundfish trawl surveys and the Fisheries Observer Program. Sampling sites ranged from Jordan Basin in the Gulf of Maine northward to Davis Strait. From Gass (2002) and Gass & Willison (2005).

Taxon	No. of Records	Average Depth (m)	Minimum Depth (m)	Maximum Depth (m)
Primnoa resedaeformis	134	319	166	467
Paragorgia arborea	41	361	249	720
Acanella arbuscula	11	622	281	1400
Paramuricea spp.	8	598	154	1159
Acanthogorgia armata	7	551	164	1400
Flabellum spp.	7	428	278	516
Keratoisis ornata	2	416	393	439
Lophelia pertusa	1	166	-	-

Table 2 Coral taxa identified by fishers from eastern Nova Scotia and Newfoundland & Labrador. From Gass (2002) and Gass & Willison (2005).

Taxon	No. of Fishers
Paragorgia arborea	15
Primnoa resedaeformis	10
Paramuricea spp.	6
Lophelia pertusa	5
Acanella arbuscula	4
Keratoisis ornata	3
Flabellum spp.	2
Bathypathes spp.	1

Video imagery was collected using Campod (a tethered video and still camera system) or ROPOS (a remotely operated vehicle) along 194 transects distributed along the shelf break between Georges Bank and the southern Grand Banks (Fig 2). Transects averaged about 600 m in length and were conducted in the general depth range of 200-500 m. Restrictions on cable length prevented surveying in deeper waters. Transect locations were selected using various sources of information including published accounts, multibeam bathymetric maps, sidescan sonograms and anecdotal sources.

Northeast Channel

Video records were collected along 52 transects in the Northeast Channel using either Campod (45 transects) or ROPOS (7 transects) (Fig 2). As described in detail by Mortensen & Buhl-Mortensen (2004), Mortensen et al. (2005) and Mortensen et al. (2006b), three Gorgonacea taxa were

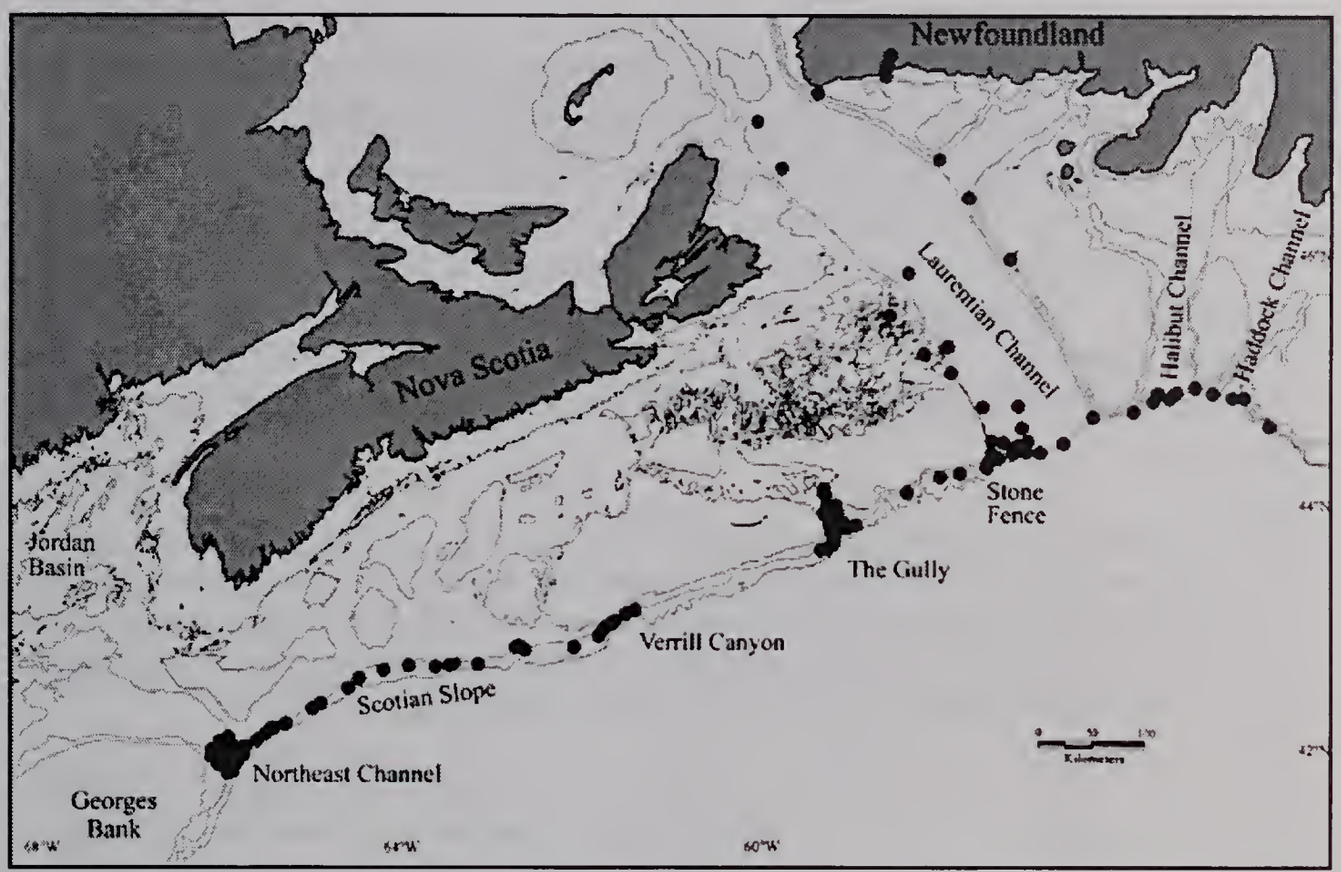

Fig 2. The location of sites in Atlantic Canada where video transects targeting deep-water corals were carried out using Campod (185 sites) or ROPOS (10 sites). Dawson Canyon is just to the east of Verrill Canyon. Not all sites had corals.

observed: *Primnoa resedaeformis*, *Paragorgia arborea* and *Acanthogorgia armata* (Table 3). *P. resedaeformis* was observed along 67% of the transects, *P. arborea* along 40% of the transects and *A. armata* along just 8% of the transects. *P. resedaeformis* was the most abundant taxon with an average abundance of 4.8 colonies per 100 m^2. The shallowest observations of *P. resedaeformis* and *P. arborea* occurred at 196 m and 235 m while their highest densities were observed between 410 and 490 m. *A. armata* was observed between 231 and 364 m.

Table 3 Summary of video observations of deep-water corals in the Northeast Channel. Taxon, number of specimens observed, the number of transects a taxon was observed on average abundance (colonies per 100 m^2), on transects where observed and depth range (m). Total number of transects was 52 and total length of all transects was 34 km. From Mortensen et al. (2005), Mortensen & Buhl-Mortensen (2004) and Mortensen et al. (2006b).

Order	Taxon	Specimens	Transects	Average Abundance	Depth Range
Gorgonacea	*Acanthogorgia armata*	212	4	0.5	231-364
	Paragorgia arborea	322	21	0.6	235-498
	Primnoa resedaeformis	2663	35	4.8	196-498

Scotian Slope

Video transects were made using Campod at 24 locations along the Scotian Slope between the Northeast Channel and Verrill Canyon (Fig 2). As described in detail by Mortensen et al. (2006b), six taxa were observed: 2 Alcyonacea and 4 Scleractinia (Table 4). The cup coral *Flabellum* spp. was the most common taxon occurring along 54% of the transects and averaging 29.2 individuals per 100 m^2. Some seapens were also observed, but no gorgonians. Four ROPOS video transects in Verrill and Dawson Canyons also indicated the presence of soft corals and cup corals but no gorgonians.

Table 4 Summary of video observations of deep-water corals along the Nova Scotian Slope. Taxon, number of specimens observed, the number of transects a taxon was observed on, average abundance (colonies or individuals per 100 m^2) on transects where observed, and depth range (m). Total number of transects was 24 and total length of all transects was 16 km. From Mortensen et al. (2006b).

Order	Taxon	Specimens	Transects	Average Abundance	Depth Range
Alcyonacea	*Duva florida*	3	2	0.01	367-427
	Nephtheidae (white)	1	1	<0.01	427
Scleractinia	*Flabellum alabastrum*	292	11	1.2	346-500
	Flabellum macandrewi	49	4	0.2	420-500
	Flabellum cf. *angulare*	303	7	1.3	346-492
	Flabellum spp.	7040	13	29.2	346-492

The Gully

Campod video transects were run at 49 sites in the Gully (Fig 2). Full details are given in Mortensen & Buhl-Mortensen (2005a) and Mortensen et al. (2006b). Except for shallow water near the head, corals were common throughout the Gully. A total of 16 taxa were identified: 5 Alcyonacea, 6 Gorgonacea and 5 Scleractinia (Table 5). Up to 11 taxa were found on a single transect. The shallowest observed depth for alcyonarians was 172 m and about 340 m for gorgonians and scleractinians. Again, nothing can be said about the maximum depths of corals because of the restrictions set by the cable length of Campod. However, photographs taken in the outer Gully using a Benthos deep-sea camera indicate that *Keratoisis ornata* extends to at least 767 m, *Radicipes* spp. to at least 1287 m, and *Anthomastus grandiflorus* to at least 1326 m (Kostylev 2000). The most abundant taxon was *Flabellum* cf. *angulare* which had an average abundance of 94.1 individuals per 100 m^2 (Table 5). The most abundant colonial coral was the soft coral *Duva florida* which had an average abundance of 5.2 colonies per 100 m^2 while the most abundant gorgonian was *Acanella arbuscula* which had an average abundance of 3.4 colonies per 100 m^2. The Gully had the highest diversity of corals of all the regions studied but the abundance of colonial corals was lower than observed in the Northeast Channel.

Table 5 Summary of video observations of deep-water corals in the Gully. Taxon, number of specimens observed, the number of transects a taxon was observed on, average abundance (colonies or individuals per 100 m^2) on transects where observed, and depth range (m). Total number of transects was 49 and total length of all transects was 17 km. From Mortensen & Buhl-Mortensen (2005a) and Mortensen et al. (2006b).

Order	Taxon	Specimens	Transects	Average Abundance	Depth Range
Alcyonacea	*Anthomastus grandiflorus*	17	6	0.2	399-523
	Duva florida	1498	18	5.2	172-537
	Nephtheidae (blue)	160	9	2.3	270-446
	Nephtheidae (white)	186	14	1.8	287-539
	Nephtheidae spp.	403	13	2.1	237-538
Gorgonacea	*Acanella arbuscula*	74	5	3.4	404-540
	Acanthogorgia armata	32	4	0.7	346-493
	Keratoisis ornata	63	8	0.9	396-509
	Paragorgia arborea	28	7	0.3	341-495
	Primnoa resedaeformis	108	4	2.0	388-516
	Radicipes gracilis	40	7	0.7	404-535
Scleractinia	*Flabellum alabastrum*	116	10	0.9	341-541
	Flabellum macandrewi	3	1	-	439
	Flabellum spp.	3396	12	12.1	404-439
	Flabellum cf. *angulare*	1124	3	94.1	337-541
	Lophelia pertusa	1	1	-	450

Stone Fence

Campod video transects were made at 39 sites at the Stone Fence in the mouth of the Laurentian Channel (Fig 2). Full details are provided in Mortensen et al. (2006b). Corals were encountered along all transects. Eight taxa were observed: 2 Alcyonacea, 4 Gorgonacea and 2 Scleractinia (Table 6). The most abundant taxon was *Duva florida* which had an

Table 6 Summary of video observations of deep-water corals at the Stone Fence in the mouth of the Laurentian Channel. Taxon, number of specimens observed, the number of transects a taxon was observed on, average abundance (colonies or individuals per 100 m2) on transects where observed, and depth range (m). Total number of transects was 39 and total length of all transects was 40 km. From Mortensen et al. (2006b).

Order	Taxon	Specimens	Transects	Average Abundance	Depth Range
Alcyonacea	*Anthomastus grandiflorus*	521	22	1.0	260-502
	Duva florida	1449	20	2.8	260-500
Gorgonacea	*Acanthogorgia armata*	288	24	1.6	260-502
	Keratoisis ornata	44	17	0.1	271-502
	Primnoa resedaeformis	297	17	0.9	260-414
	Paragorgia arborea	115	20	0.4	260-502
Scleractinia	*Lophelia pertusa* (live)	67	8	0.01	260-400
	Flabellum spp.			0.2	

average abundance of 2.8 colonies per 100 m^2. Of particular note at this site was the discovery of a *Lophelia pertusa* reef complex approximately 490 by 1300 m (about 0.6 km^2) comprised of live colonies, dead blocks and skeletal rubble. Most of the living colonies were observed between 300 and 320 m. Dead *L. pertusa*, both rubble and blocks, was much more abundant than living coral. This marked the first time that *L. pertusa* has been seen alive in its natural habitat in Atlantic Canada. In general, both the abundance and diversity of corals at the Stone Fence were lower than found in the Gully.

Laurentian Channel

Campod video transects were run at 19 sites in the Laurentian Channel (Fig 2). Full details are given in Mortensen et al. (2006b). Corals were found along 45% of the transects. Seven taxa were identified: 2 Alcyonacea, 3 Gorgonacea and 2 Scleractinia (Table 7). Depth range was 245-414 m. In general, the abundance of corals was low with a maximum for *Acanthogorgia armata* of 1.1 colonies per 100 m^2.

Table 7 Summary of video observations of deep-water corals in the Laurentian Channel (excluding the Stone Fence region). Taxon, number of specimens observed, the number of transects a taxon was observed on, average abundance (colonies or individuals per 100 m2) on transects where observed, and depth range (m). Total number of transects was 19 and total length of all transects was 7.2 km. From Mortensen et al. (2006b).

Order	Taxon	Specimens	Transects	Average Abundance	Depth Range
Alcyonacea	*Duva florida*	8	1	1.0	340
	Gersemia rubiformis	17	1	0.5	245
Gorgonacea	*Acanthogorgia armata*	60	1	1.1	340
	Acanella arbuscula			0.3	
	Radicipes gracilis	1	1	0.1	348
Scleractinia	*Flabellum alabastrum*	34	4	0.7	305-414
	Flabellum spp.	54	7	0.6	305-414

Southern Edge of the Grand Banks

Campod video transects were run at 11 sites in the Haddock and Halibut Channels along the southern edge of the Grand Banks (Fig 2). Full details are given in Mortensen et al. (2006b). Corals were found along 64% of the transects. Eight taxa were identified: 3 Alcyonacea, 3 Gorgonacea and 2 Scleractinia (Table 8). In general, abundance was low with the most abundant taxon being *Flabellum alabastrum* which had an average abundance of 1.9 colonies per 100 m^2.

Table 8 Summary of video observations of deep-water corals in the Haddock and Halibut Channels along the southern edge of the Grand Banks. Taxon, number of specimens observed, the number of transects a taxon was observed on, average abundance (colonies or individuals per 10 m2) on transects where observed, and depth range (m)s. Total number of transects was 11 and total length of all transects was 4.2 km. From Mortensen et al. (2006b).

Order	Taxon	Specimens	Transects	Average Abundance	Depth Range
Alcyonacea	*Anthomastus grandiflorus*	2	1	0.1	421
	Duva florida	107	4	1.5	504
	Nephtheidae (white)	16	4	0.3	409
Gorgonacea	*Acanella arbuscula*	169	2	0.1	409-421
	Acanthogorgia armata	38	6	0.4	370-518
	Radicipes gracilis	15	1	0.9	409
Scleractinia	*Flabellum alabastrum*	177	4	1.9	409-518
	Flabellum spp.	158	5	1.3	370-518

All taxa observed during this program are listed in Table 9. A total of 19 taxa were positively identified including 6 Alcyonacea, 7 Gorgonacea, 5 Scleractinia and 1 Antipatharia. All these taxa were observed in the video footage except *Paramuricea* spp. and *Bathypathes* spp. None of the Alcyonacea taxa were detected in the groundfish surveys and observer program or by fishers, data sources which are dependent on fishing gear. These taxa are relatively small in size and they were probably not caught, ignored or misidentified. While much more costly, video surveys are obviously the preferred option, especially since they are non-destructive and provide quantitative data. Additional taxa have been reported to occur in Atlantic Canada (Breeze et al. 1997 and Mortensen et al. 2006b) but were not observed during this program. Further field studies should confirm the occurrence of additional deep-water coral taxa and extend the ranges of those already confirmed.

HABITAT CHARACTERISTICS

Northeast Channel

As reported by Mortensen & Buhl-Mortensen (2004) and Mortensen et al. (2005b), the distribution of the three gorgonian species observed (*Primnoa resedaeformis*, *Paragorgia arborea*, and *Acanthogorgia armata*) was patchy and restricted to areas with cobbles and boulders. No corals were observed attached to sand or pebbles. Boulders were commonly observed on most transects but seldom covered more than 50% of the seabed. For all transects, the percent cover of cobble and boulder averaged 21% and 9%, respectively. Many boulders had no corals attached indicating that suitable substrate is not limiting. Large colonies of *P. arborea* were observed almost exclusively on boulders, whereas smaller colonies were often observed on cobbles as well. *P. resedaeformis* occurred on both cobbles and boulders,

Table 9 Deep-water coral taxa identified during this program (2001-2003) according to data source.

Order	Taxon	Groundfish Surveys and Observer Program	Fishers	Video
Alcyonacea	*Anthomastus grandiflorus*			X
	Duva florida			X
	Gersemia rubiformis			X
	Nephtheidae (blue)			X
	Nephtheidae (white)			X
	Nephtheidae spp.			X
Gorgonacea	*Acanella arbuscula*	X	X	X
	Acanthogorgia armata	X		X
	Keratoisis ornata	X	X	X
	Paragorgia arborea	X	X	X
	Primnoa resedaeformis	X	X	X
	Radicipes gracilis			X
	Paramuricea spp.	X	X	
Scleractinia	*Flabellum alabastrum*			X
	Flabellum macandrewi			X
	Flabellum spp.	X	X	X
	Flabellum cf. angulare			X
	Lophelia pertusa	X	X	X
Antipatharia	*Bathypathes* spp.		X	

while *A. armata* was found only on cobbles. Both *P. resedaeformis* and *P. arborea* were frequently found on the same boulder. There was no sign of competitive exclusion at any spatial scale.

Corals were more common in the outer part of the Channel compared to the inner (Mortensen & Buhl-Mortensen 2004). Transects with the highest abundance of corals were characterized by depths greater than 400 m, a maximum water temperature less than 9.2 °C, and a relatively high percent coverage of cobble and boulders. High temperatures probably control the upper depth limit of the corals. *Primnoa resedaeformis* seems to tolerate slightly higher temperatures than *Paragorgia arborea* (about 13 °C compared to about 10 °C). Abundance of both species was negatively correlated with average temperature and positively correlated with cobbles. Together, temperature, percent cobble and salinity accounted for 38% of the variance of *P. resedaeformis* compared to 15% for *P. arborea*. The overall distribution of corals appears to be related to the general circulation. Corals were almost totally absent on the northern side along the flanks of Browns Bank which has a net inflow whereas they were most abundant on the southern side which has a net outflow (Ramp et al. 1985).

Scotian Slope

The seabed at the slope transects examined was composed of soft sediments (Mortensen et al. 2006b). The only hard substrate was some very sparse cobble. No boulders were observed. Individuals of the dominant taxon (*Flabellum* spp.) were small and unattached. When observed, the soft coral *Duva florida* was attached to cobble.

The Gully

As described by Mortensen & Buhl-Mortensen (2005a), the Gully has a high diversity of habitats including steep bedrock outcrops, high relief ledges, gravel, sand and mud. The area of cobble and boulder (9%) was much less than observed in the Northeast Channel (21%). Sand was more common in the shallow inner part of the Gully while mud was more common in the deeper outer part. Sharp changes in substrate were often related to changes in slope. Bottom temperature in the Gully ranged between 1.9 and 10.3 C and averaged 5.3 C. Salinity was generally between 34.55 and 34.86.

Corals were found in most parts of the canyon (Mortensen & Buhl-Mortensen 2005a and Mortensen et al. 2006b). Most were found deeper than 350 m. Substrate in the shallow inner Gully consists mainly of muddy sand. The only corals observed were alcyonarians attached to scattered cobbles. In other parts of the Gully above the shelf break, the seabed was muddier and *Flabellum* spp. was abundant. Below the shelf break, the seabed becomes coarser and has patches of gravel that support a great diversity of suspension feeders. Here, the gorgonian *Acanthogorgia armata* and the alcyonarian *Anthomastus grandiflorus* were observed on cobbles and boulders. On transects in small side canyons, a rugged terrain was observed with extensive outcrops of semi-consolidated mudstone. Soft corals were situated on the crests of these structures, also *Paragorgia arborea* and *Primnoa resedaeformis* where mudstone was exposed. Elsewhere, *P. arborea* and *P. resedaeformis* were more commonly found on boulders. The gorgonian *Keratoisis ornata* was often observed on cobbles and boulders in the bottom of small channels. *Flabellum* spp. and *Acanella arbuscula* were generally associated with the finer, more level sediments in the outer part of the Gully. *K. ornata*, *P. resedaeformis* and Nephtheidae spp. were associated with steep slope and exposed mudstone. Except for *A. arbuscula* and *Radicipes gracilis*, which are anchored in soft sediment, gorgonians were mainly confined to areas with cobble and boulders, and in a few cases semi-consolidated mudstone. On the other hand, the soft corals utilized a wide range of substrates including the semi-consolidated mudstone.

Multivariate analyses by Mortensen & Buhl-Mortensen (2005a) indicated that the distribution of corals in the Gully is controlled primarily by distance along the axis, salinity, substrate type and slope. However, much of the variation in coral distribution could not be accounted for by environmental variables. As in the Northeast Channel, the highest abundance of corals is found on the western side of the canyon and this is presumably related to residual circulation patterns.

Stone Fence

The video observations indicated the presence of a *Lophelia pertusa* reef complex of smaller coral mounds within an area of approximately 490 x 1300 m (Mortensen et al. 2006a). Locally, *L. pertusa* rubble, with some infill of finer sediment, covered up to 100 % of the bottom. *L. pertusa* oc-

curred as live or dead fragments in clusters in isolated rubble areas typically extending horizontally 10 to 100 m. These rubble areas probably represent former reefs. The height of these accumulations of coral (both rubble and larger dead fragments) was difficult to measure but was estimated to be about 3 m. Relatively small colonies of *Paragoria arborea* were observed and many of these were tilted or attached to the sides of boulders. The location of the reef complex on the western side of the mouth of the Laurentian Channel is thought to be due in part to higher food concentrations in outflowing water.

Laurentian Channel

In general, the relatively low abundance of corals in the Laurentian Channel probably reflects the low cover of cobble and boulder in this area (Mortensen et al. 2006b).

MORPHOLOGY, GROWTH, AND BEHAVIOUR

As described by Mortensen & Buhl-Mortensen (2005b), the height of *Paragorgia arborea* colonies ranged from 5 to 180 cm with an average of 57 cm, while the height of *Primnoa resedaeformis* colonies ranged from 5 to 86 cm with an average of 30 cm. There was a significant correlation between height and base diameter for both species. *P. arborea* colonies generally had thicker trunks and branches than *P. resedaeformis*. Most *P. arborea* colonies were more or less circular in outline while *P. resedaeformis* colonies were more oblong with conical branches widening at the top. The height of *P. arborea* colonies was positively correlated to the size of the boulders to which they were attached. It appears that when maximum height exceeds approximately twice the diameter of the boulder, strong currents can roll them over resulting in a changed growth direction. A similar relation has been reported in Knight Inlet, British Columbia (Tunnicliffe & Syvitsky 1983).

Paragorgia arborea was observed to occur in three colour varities: salmon, red and white (Mortensen & Buhl-Mortensen 2005b). The red and white varieties each contributed 41% to the population while 18% of the colonies were salmon-coloured. On average, salmon-coloured *P. arborea* colonies were taller than the red and white varieties. As the varieties co-occur, these differences in colour are thought to be related to genetics and not environmental factors.

Most *Paragorgia arborea* colonies larger than 50 cm were concave-shaped and oriented into the prevailing near-bottom current (Mortensen & Buhl-Mortensen 2005b). Polyp density was higher for *Primnoa resedaeformis* than *P. arborea* but for both species polyp density was greatest on the outer branches. *P. arborea* most commonly occurred on the top of boulders. *P. resedaeformis* did not reflect the main current direction to the same degree as *P. arborea* but commonly occurred on the up-current side of boulders. The different height, morphology and position on boulders of

these two gorgonian species suggests they utilize different food sources. *P. resedaeformis* seems to be adapted to a near bottom environment with turbulent currents while *P. arborea* seems more adapted to uni- or bi-directional currents higher off the seabed and develops planar colonies perpendicular to the prevailing current. The orientation of large *P. arborea* colonies provides a picture of near bottom-current patterns integrated over long time spans. In the Northeast Channel, their parabolic colony form was observed to face into the outflowing current, presumably to maximize the capture of food particles.

Based on counting the rings in cross-sections of colony bases, the oldest *Primnoa resedaeformis* colony collected was 61 years (Mortensen & Buhl-Mortensen 2005b). The relationship between height and age indicated an average growth rate of 1.7 cm/y for *P. resedaeformis*. X-ray images of skeletal sections of *Paragorgia arborea* showed clear growth bands but since it was not certain what time scales these bands indicated they could not be used for ageing. However, other data sources reviewed by Mortensen & Buhl-Mortensen (2005b) suggest an average growth rate of approximately 1 cm/year. This means that the largest *P. arborea* colony measured in this study (180 cm in height) was on the order of 180 years old.

Live specimens of *Flabellum alabastrum*, *Duva florida*, *Anthomastus grandiflorus*, *Primnoa resedaeformis*, *Keratoisis ornata*, *Acanella arbuscula*, *Acanthogorgia armata*, and *Paragorgia arborea* were successfully collected by ROPOS and Videograb and transported to the BIO Fish Lab. *D. florida* and *F. alabastrum* turned out to be the easiest taxa to maintain in aquaria and some specimens survived as long as 21 months feeding on unfiltered Bedford Basin water which contained abundant zooplankton and organic particles. This experience indicates that it is feasible to conduct experiments on deep-water corals if healthy specimens can be obtained, especially *D. florida* and *F. alabastrum*.

Laboratory observations were made on the behaviour of *Duva florida, Flabellum alabastrum* and *Anthomastus grandiflorus*, in particular patterns in body extension and contraction. The results indicate that there are differences in feeding behaviour and that the ability to handle food particles of different size seems to be related to the anatomy of the polyps. One observation of note is the ability of *F. alabastrum* to expand its body size more than ten times. This behaviour may be related to food uptake and physiology, or it may represent a way of escaping an area by increasing buoyancy and drag and moving with the bottom current. This behaviour was also observed in the field. *F. alabastrum* was also observed to move slowly, leaving tracks in the sediment, but the mechanism for doing this is not understood. The respiration rate of *F. alabastrum* was measured and found to be quite low.

ASSOCIATED FAUNA

Deep-water corals provide structural habitat that can be used by other species. This includes the surface of living and dead corals, cavities inside dead skeletons and the spaces between coral branches. Branches can reach up into stronger currents above the benthic boundary layer and feeding advantages are shared with attached filter-feeding organisms. Associated species can also feed on detritus and micro-organisms trapped in coral mucous.

A literature review revealed that more than 980 species have been recorded on deep-water corals (Buhl-Mortensen & Mortensen 2004a). Of these, 112 can be characterized as symbionts of which 30 species are obligate to corals. Fifty-three percent of these obligates are parasites and 47% are commensals. There are no clear examples of symbiotic relationships.

A total of 114 invertebrate species were recorded from 25 specimens of *Paragorgia arborea* and *Primnoa resedaeformis* collected by ROPOS, Videograb, and otter trawls in the study area (Buhl-Mortensen & Mortensen 2005). The fauna associated with *P. resedaeformis* was more diverse and abundant than that associated with *P. arborea* and the taxonomic composition of associates was quite different for the two taxa. Rarefaction analysis indicated that many more associated species are still to be found. The numbers of species and individuals were significantly correlated with coral morphology (e.g. number of branches, wet weight, percent exposed skeleton). Crustaceans dominated the fauna, contributing 46% of the total number of individuals and 26% of the total number of species. Two coral microhabitats were identified: young and live parts of colonies, and old parts with deposits and exposed skeleton. Most of the associated fauna was found in the latter microhabitat. Sessile hydroids, anemones and molluscs were more abundant on *P. resedaeformis* and were attached to exposed skeleton. Parasitic copepods were more common on *P. arborea*. The basket star *Gorgonocephalus lamarckii* was found on the outer branches of *P. arborea* in high current environments. The shrimp *Pandalus propinquus* was found within colonies of both species.

In the Northeast Channel, a parasitic colonial zoanthid anemone was the most common sessile epibiont observed on *Primnoa resedaeformis* (Mortensen et al. 2005). On average, it covered about 60% of the surface of the 28 infected colonies, but one third of the colonies were entirely covered. Hydroids were also frequently found on *P. resedaeformis* (represented with 12 species), but were less common on *Paragorgia. arborea* (three species). Henry (2001) reports that thirteen hydroid species were found on four coral specimens collected off Atlantic Canada.

Seventeen species of associated crustaceans were identified in seven colonies of *Paragorgia arborea* and eight colonies of *Primnoa resedaeformis* sampled with the suction sampler on ROPOS in the depth range of 330-500 m in the Northeast Channel (Buhl-Mortensen & Mortensen 2004b). The *P. arborea* fauna was richer than the *P. resedaeformis* fauna in both

number of species and abundance. Amphipods dominated the fauna but isopods and cirripeds were also common. The most strongly associated crustaceans were two parasitic copepods belonging to a family which is also found on tropical gorgonians and are most likely obligate associates. Shrimp also occurred frequently and most likely seek protection among coral branches from predation. The numerical dominance of amphipods and parasitic copepods is similar to observations made on tropical shallow-water gorgonians but the species richness is higher.

Many of the associated taxa are also found on tropical gorgonians but the deep-water gorgonians lack the diverse decapod and gastropod fauna of their tropical counterparts. The richness of species associated with deep-water gorgonians appears to be higher than reported for tropical shallow-water gorgonians. In contrast to tropical shallow-water gorgonians, deep-water gorgonians have very few obligate symbionts. Nevertheless, several of the species are rare in other habitats and some have been recorded on the same and other gorgonian species in earlier studies.

A new genus and species of a gall-forming parasitic copepod (*Gorgonophilus canadensis*) was discovered on specimens of *Paragorgia arborea* collected from approximately 500 m in the Northeast Channel by ROPOS and in the Davis Strait by a groundfish trawl survey (Buhl-Mortensen & Mortensen 2004c). Infection of this endoparasite seems to have little effect on the host. A new species of pedunculate barnacle (*Heteralepas cantelli*) was discovered on a specimen of *Primnoa resedaeformis* collected by otter trawl at a depth of about 500 m on the Scotian Slope (Buhl-Mortensen & Newman 2004). This is the most northern record of this genus. The gorgonian *Trachythela rudis* was observed for the first time off Nova Scotia. It occurred as an epizoic on a *P. resedaeformis* skeleton. Previously, it is known from the fishing banks off Newfoundland (Verrill 1922, Deichmann 1936).

Various taxa of fish were commonly seen associated with corals in the video imagery. The most common was the redfish (*Sebastes* spp.) which is widely distributed in deep water through out Atlantic Canada, including sites without abundant corals. In the Northeast Channel, redfish were almost four times as common in video sequences with corals than in sequences with boulders but not corals (Mortensen et al. 2005). Twelve taxa of fish were observed along the video transects in the Gully (Mortensen & Buhl-Mortensen 2005a). Like the Northeast Channel, the most common species was redfish (*Sebastes* spp.) which was found on 68% of the transects. The second most common species was the long-finned hake (*Urophycis chesteri*) which was found on 51% of the transects. Redfish were abundant at the site of the *Lophelia* reef complex at the Stone Fence but the relationship with corals was not significant (Mortensen et al. 2006a).

DAMAGE BY FISHING GEAR

Fishing gear coming into contact with the seabed has the potential to damage corals, especially the larger taxa (Freiwald et al. 2004). Corals

are commonly caught as bycatch during commercial fishing operations and research trawl surveys (Table 1). Damaged corals can also be left behind out of sight on the seabed (Mortensen et al. 2005 and Mortensen et al. 2006a). The extent and significance of this damage is currently a matter of debate. Coral communities can probably tolerate a low magnitude and frequency of damage but their slow growth rate of just a few cm/y (Mortensen and Buhl-Mortensen 2005b) means that recovery times will be tens to hundreds of years.

Northeast Channel

As reported by Mortensen et al. (2005), signs of fishing impact in the Northeast Channel were visible as broken live corals, tilted corals and scattered skeletons. Broken or tilted corals were observed on 29% of the transects and were not concentrated in any particular area. In total, 4% of the observed colonies were damaged. A higher percentage of *Paragorgia arborea* colonies was damaged compared to *Primnoa resedaeformis* (7.9% versus 3.4%). This is most likely due to its larger size and less flexible skeleton. It appears that damage may make corals more susceptible to parasites since the parasitic anemone was more common on damaged colonies of *P. resedaeformis* than intact ones. Lost longlines were observed loose on the seabed or entangled in corals on 37% of the transects. Tracks on the seabed, either from longline anchors or parts of otter trawl gear, were present along three transects, while lost gillnets were observed along two transects. With one exception, longlines were only found on transects where coral were present.

Scotian Slope

No signs of damage to corals were observed in the video footage along the Scotian Slope transects (Mortensen et al. 2006a) despite the fact that the distribution of trawling effort indicates that this region has been quite heavily fished in recent years (Kulka & Pitcher 2001). This is probably because the dominant species are small, free-living cup corals which are less prone to damage from fishing gear than other coral taxa.

The Gully

Few signs of fishing damage were observed in the Gully, just a few trawl tracks and one corroded lost wire from a trawl (Mortensen et al. 2006a). Spatial analysis of observer data by Kulka & Pitcher (2001) indicates that the general area of the Gully was heavily fished with otter trawls during the 1980s and early 1990s but that trawling effort then dropped significantly with very little activity in 1998-2000. Canyons are naturally protected against bottom trawling to some degree because of their rugged topography.

Stone Fence

The *Lophelia pertusa* reef complex at the Stone Fence was clearly impacted by fishing gear (Mortensen et al. 2006a). All live colonies were either small or clearly broken in an unnatural way. A large rubble zone was evident and

unusual amounts of pale grey skeletons were present. Gorgonians also showed signs of disturbance in the form of their small size and unnatural occurrence on the sides of and underneath boulders. Many cobbles and boulders showed signs of being overturned. A fragment of a trawl net was also found. Spatial analysis of observer data indicated that the general area of the *L. pertusa* reef was regularly trawled between 1980 and 2000.

DISCUSSION

This three-year DFO research project, funded in part by the oil and gas industry, has produced a wealth of new information on the distribution, abundance, habitat and biology of deep-water corals in Atlantic Canada. Data were obtained from DFO groundfish surveys, the Fisheries Observer Program, interviews with fishers and dedicated DFO research cruises with specialized imaging and sampling equipment. The results are in general agreement with the observations of Breeze et al. (1997) but provide much more detail. Nineteen coral taxa were observed. The results confirmed the importance of the Northeast Channel, Gully and Stone Fence as prime coral habitats off Nova Scotia but also demonstrated their abundance off Newfoundland & Labrador as well as their occurrence at least as far north as Davis Strait. Coral abundance was greatest in the Northeast Channel while diversity was greatest in the Gully. The discovery of the *Lophelia* reef complex at the Stone Fence marked the first time this taxon has been seen alive in its natural habitat in Atlantic Canada. The most important environmental factors controlling the distribution of corals appear to be substrate, temperature, salinity and currents (which influence food supply). The average height of *Primnoa* and *Paragorgia* colonies was 30 and 57 cm so, at their estimated growth rates of 1.7 and 1 cm /year, the largest *Primnoa* colony observed was about 61 years old while the largest *Paragorgia* colony was about 180 years old. A rich associated fauna of 114 taxa was identified on *Paragorgia* and *Primnoa*. Numerous species of fish were also observed associated with deep-water corals, in particular redfish. Damage from fishing gear was most evident at the *Lophelia* reef complex at the Stone Fence and on gorgonians in the Northeast Channel.

Globally, our understanding of deep-water coral ecosystems and the processes regulating their distribution and behaviour is rudimentary. Nevertheless, it is clear that they represent important biodiversity hotspots and a biological resource with intrinsic and socio-economic value. Because of their longevity, slow growth rates and fragility, they are especially vulnerable to physical damage, in particular bottom fishing activity. Therefore, there is an urgent need to apply some protection from human disturbance.

In 2002, DFO and the fishing industry formed a working group to consider coral protection for the Northeast Channel. After reviewing the results of the video surveys, DFO proposed boundaries for a coral conservation area centered on Romeys Peak because of its high abundance of gorgonians. A fisheries assessment was conducted using available data and discus-

sions with the working group and at a public meeting led to a greater understanding of the overlap between fishing activities and coral abundance. Adjustments were made to the design of the conservation area taking into consideration the concerns of fishing organizations. A coral conservation area, 424 km^2 in size, was formally established by DFO in June 2002 (Mortensen et al. 2005) and slightly modified in 2003. With the exception of 10% of the area which is open to longline gear, the entire area is closed to all bottom fishing gear.

The results of this project have confirmed earlier observations (Breeze et al. 1997, MacIsaac et al. 2001) that the Gully is indeed a special habitat for deep-water corals. While the average abundance of corals is less than in the Northeast Channel, on the basis of the available data , the species diversity appears to be much greater (compare Table 3 and Table 5). The importance of corals in the Gully played a role in the design of the large Marine Protected Area (2364 km^2) that was formally announced by DFO in May 2004.

The discovery of the *Lophelia* reef complex at the Stone Fence, heavily damaged by fishing activity, led to immediate discussions and meetings regarding establishing a coral conservation area. The need for such a closure to prevent further damage and allow recovery was recognized by all parties, including the fishing industry. After considerable consultation, a 15 km^2 coral conservation area centered over the reef complex was established by DFO in June 2004 (Mortensen et al. 2006a).

There still is much that needs to be learned about deep-water corals in Atlantic Canada and research is being continued by DFO and universities. Research priorities have been identified in the Maritimes Region coral conservation plan (DFO 2006). These include continuing to identify important deep-water coral areas, especially at depths below 500 m which have been poorly sampled to date. Opportunistic sampling of corals continues through the DFO trawl surveys and Fisheries Observer Program in all regions which provide valuable data and samples at practically no cost. Sea-going staff are provided with coral information sheets to improve identification. A coral distribution data base is maintained and updated regularly as new data are obtained. As part of the Discovery Corridor program (Kenchington & Lawton 2006), coordinated by the Centre of Marine Biodiversity, DFO, Dalhousie University and Memorial University are studying deep-water corals and their habitats in the Jordan Basin, Georges Basin and Northeast Channel using both Campod and ROPOS. The 2006 ROPOS cruise provided the first opportunity to observe corals deeper than 500 m. DFO in the Newfoundland & Labrador Region has established a long-term research program in collaboration with Memorial University which is placing emphasis on distributional and abundance studies off Newfoundland & Labrador. It is expected that there will continue to be annual coral research cruises on the C.C.G.S. *Hudson* to areas of particular interest using both Campod and Videograb (which now have a new 800 m cable) and ROPOS. These programs will undoubtedly expand our knowledge of deep-water corals still

further, particularly in regions not yet sampled adequately and at depths greater than 500 m. As well as increasing scientific understanding, these new data will further assist oceans managers in protecting deep-water corals from human disturbance.

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REFERENCES

Breeze H, Davis DS, Butler M, Kostylev V (1997) Distribution and status of deep sea corals off Nova Scotia. Marine Issues Committee Special Publication No 1, Ecology Action Centre, Halifax, NS

Buhl-Mortensen L, Mortensen PB (2004a) Symbiosis in deep-water corals. Symbiosis 37:3-61

Buhl-Mortensen L, Mortensen PB (2004b) Crustaceans associated with the deep-water gorgonian corals *Paragorgia arborea* (L., 1758) and *Primnoa resedaeformis* (Gunn. 1763). J Nat Hist 38:1233-1247

Buhl-Mortensen L, Mortensen PB (2004c) *Gorgonophilus canadensis* n. gen., n. sp. (Copepoda: Lamippidae), a gall forming endoparasite in the octocoral *Paragorgia arborea* (L., 1758) from the Northwest Atlantic. Symbiosis 37:155-168

Buhl-Mortensen L, Mortensen PB (2005) Distribution and diversity of species associated with deep-sea gorgonian corals off Atlantic Canada. In: Freiwald A, Roberts JM (eds) Cold-water corals and ecosystems. Springer-Verlag, Berlin, p 849-879

Buhl-Mortensen L, Newman WA (2004) A new pedunculate barnacle (Cirripedia: Heteralepadidae) from the Northwest Atlantic Ocean. Proc Biol Soc Washington 117:385-397

Deichmann E (1936) Alcyonaria of the Western Part of the Atlantic Ocean. Memoirs of the Museum of Comparative Zoology, Harvard University, Cambridge, MA

DFO (Department of Fisheries and Oceans) (2006) Coral conservation plan; Maritimes Region (2006-2010). Oceans and Coastal Management Report 2006-01

Freiwald A., Fosså JH, Grehan A, Koslow T, Roberts JM (2004) Cold-water coral reefs. UNEP-WCMC Biodiversity Ser No 22, Cambridge, UK

Gass SE (2002) An assessment of the distribution and status of deep-sea corals in Atlantic Canada by using both scientific and local forms of knowledge. MSc thesis, Dalhousie University, Halifax, NS

Gass SE, Willison JMH (2005) An assessment of the distribution of deep sea corals in Atlantic Canada by using both scientific and local forms of knowledge. In: Freiwald A, Roberts JM (eds) Cold-water corals and ecosystems. Springer-Verlag, Berlin, p 223-245

Henry L-A (2001) Hydroids associated with deep-sea corals in the boreal north-west Atlantic. J Mar Biol Assoc UK 81:163-164

Kenchington E, Lawton P (2006) The Discovery Corridor – Exploring our continental shelf and deep-water ecosystems. In: Ryan J (ed) Bedford Institute of Oceanography Annual Review 2005. DFO & NRCan, Dartmouth, NS, p 43-46

Kostylev VE (2000). Data base on underwater imagery from the Sable Island Gully. Contractors report prepared for DFO, Dartmouth, NS

Kulka DW, Pitcher DA (2001) Spatial and temporal patterns in trawling activity in the Canadian Atlantic and Pacific. Int coun Explor Sea CM 2001/R:02

MacIsaac K, Bourbonnais C, Kenchington E, Gordon DC Jr, Gass S (2001) Observations on the occurrence and habitat preference of corals in Atlantic Canada. In: Willison JHM, Hall J, Gass SE, Kenchington ELR, Butler M, Doherty P (eds) Proceedings of the First International Symposium on Deep-Sea Corals. Ecology Action Centre and Nova Scotia Museum, Halifax, NS, p 58-75

Mortensen PB, Buhl-Mortensen L (2004) Distribution of deep-water gorgonian corals in relation to benthic habitat features in the Northeast Channel (Atlantic Canada). Mar Biol 144:1223-1238

Mortensen PB, Buhl-Mortensen L (2005a) Deepwater corals and their habitats in The Gully, a submarine canyon off Atlantic Canada. In: Freiwald A, Roberts JM (eds) Cold-water corals and ecosystems. Springer-Verlag, Berlin, p 247-277

Mortensen PB, Buhl-Mortensen L (2005b) Morphology and growth of the deep-water gorgonians *Primnoa resedaeformis* and *Paragorgia aborea.* Mar Biol 147:775-788

Mortensen PB, Buhl-Mortensen L, Gordon DC Jr, Fader GBA, McKeown DL, Fenton DG (2005) Effects of fisheries on deepwater gorgonian corals in the Northeast Channel, Nova Scotia. Am Fish Soc Symp 41:369-382

Mortensen PB, Buhl-Mortensen L, Gass SE, Gordon DC Jr, Kenchington ELR, Bourbonnais C, MacIsaac KG (2006a) Deep-water corals in Atlantic Canada: A summary of ESRF-funded research (2001-2003). Can Gov't Environmental Studies Research Fund Report 143

Mortensen PB, Buhl-Mortensen L, Gordon DC Jr (2006b) Distribution of deep-water corals in Atlantic Canada. In: Suzuki Y, Nakamori T, Hidaka M, Kayanne H, Casareto BE, Nadaoka K, Yamano H, Tsuchiya M (eds) Proceedings of the 10th International Coral Reef Symposium. Japanese Coral Reef Society, Tokyo, p 1832-1848

Ramp SR, Schultz RJ, Wright WR (1985) The deep flow through the Northeast Channel, Gulf of Maine. J Phys Oceanogr 15:1790-1808

Tunnicliffe V, Syvitski JPM (1983) Corals move boulders: an unusual mechanism of sediment transport. Limnol Oceanogr 28:564-568

Verrill AE (1922) The Alcyonaria of the Canadian Arctic expedition, 1913-1918, with a revision of some other Canadian genera and species. Report of the Canadian Arctic Expedition 1913-18, Volume 8: Molluscs, echinoderms, coelenterates, etc, Part G: Alcyonaria and actinaria. FA Acland, Ottawa, ON

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BIOLOGICAL AND ENVIRONMENTAL REQUISITES FOR A SUCCESSFUL TRAP FISHERY OF THE NORTHERN SHRIMP *Pandalus borealis*

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A permanent trap fishery for northern pink shrimp (*Pandalus borealis*) was established in Chedabucto Bay, Nova Scotia in 1996 after several years of experimental trapping by one fisherman. Despite extensive experimental trapping projects elsewhere in Nova Scotia, only in one other area, Mahone Bay, has a long-term fishery been successfully established. The successful trapping of shrimp from small vessels off the coast of Nova Scotia appears to be dependant on a number of requisite conditions, including the presence of soft mud habitat and low temperatures in large, relatively deep coastal embayments. Catch rates for the established inshore trap fisheries increase in late summer-fall and decrease in spring, suggesting that an inshore migration occurs in the fall from adjacent "feeder" populations. In addition to the seasonal pattern of trap catches, cyclical changes at a finer temporal scale were observed that appear to be related to tidal cycles, with higher catch rates associated with greater tidal ranges. Coupled with known diurnal vertical migratory behaviour, this pattern could arise as more water, and the shrimp within it, pass horizontally over the trap and come into contact with its bait plume during greater tidal ranges. More complex, selective vertical migration coupled with tidal drift may result in net movement into areas such as Chedabucto Bay. Analysis of length at sex transition and maximum size suggests that shrimp trapped in Chedabucto Bay come from the same population as those caught by trawlers inshore and offshore on the eastern Scotian Shelf. Shrimp trapped in Mahone Bay and St. Margaret's Bay have significantly different growth characteristics and are probably from a different population. Thus the Mahone Bay and St. Margaret's Bay population appears to be more locally confined than the widespread shrimp population on the eastern Scotian Shelf, possibly originating from areas within and immediately adjacent to these bays.

Une pêche annuelle de la crevette nordique (*Pandalus borealis*) au casier a été établie dans la baie Chedabucto (Nouvelle-Écosse) en 1996, après plusieurs années de pêche expérimentale au casier par un pêcheur. Malgré les nombreux projets de pêche expérimentale au casier menés ailleurs dans la province, une pêche à long terme a été établie avec succès dans seulement un autre secteur (la baie Mahone). La réussite de la pêche de la crevette au casier par les petits bateaux au large de la côte de la Nouvelle-Écosse semble dépendre d'un certain nombre de conditions, y compris la présence d'un habitat vaseux mou et de basses températures dans de grandes échancrures relativement profondes de la côte. Les taux de capture pour les pêches côtières au casier établies augmentent à la fin de l'été et à l'automne et baissent

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au printemps, ce qui suggère que les crevettes migrent de populations sources vers la côte à l'automne. En plus de ce profil saisonnier des prises dans les casiers, des changements cycliques à une échelle temporelle plus fine ont été observés et ceux-ci semblent liés au cycle de marée, le taux de capture étant plus élevé lorsque l'amplitude de la marée est grande. Combiné au comportement de migration verticale diurne, ce profil pourrait survenir quand la quantité d'eau (et les crevettes qu'elle contient) qui passe horizontalement au-dessus des casiers est grande et qu'elle entre en contact avec le panache d'attractifs des casiers durant les périodes de grande amplitude de la marée. Une migration verticale sélective plus complexe combinée à une dérive tidale pourrait donner lieu à un mouvement net vers les secteurs comme la baie Chedabucto. L'analyse de la longueur au moment du changement de sexe et de la taille maximale suggère que les crevettes piégées dans la baie Chedabucto appartiennent à la même population que celles capturées par les chalutiers en milieux côtiers et extracôtiers dans la partie est du plateau néo-écossais. Les crevettes piégées dans les baies Mahone et St. Margaret's ont des caractéristiques de croissance considérablement différentes et font probablement partie d'une autre population. Ainsi, la population des baies Mahone et St. Margaret's semble avoir une aire de répartition beaucoup plus limitée que la population étendue de crevettes dans la partie est du plateau néo-écossais, et elle provient peut-être de secteurs à l'intérieur de ces baies ou adjacents à celles-ci.

INTRODUCTION

Late in 2006 Mike Newell, a fisherman from Canso, Nova Scotia, died at sea while tending to shrimp traps in the small but thriving fishery he founded. This paper, and a companion article published in the Bedford Institute of Oceanography's annual Science Review, are dedicated to him. Much of the data used were collected by him during his experimental and commercial fishing endeavours.

Pandalus borealis, the northern pink shrimp, is a circumpolar species. On the Scotian Shelf it is near the southern limit of its distribution where commercial concentrations are currently restricted mainly to the cold, deep water of the eastern Scotian Shelf. It is a protandric hermaphrodite, which spends approximately its first four years as a male, then changes to the female at about 20mm carapace length. The larger females usually comprise the bulk of the commercial catch. The fishery for northern shrimp in the Maritime Provinces first began in the mid 1960s off Grand Manan Island in the Bay of Fundy. By the end of the decade catches had dwindled and the shrimp trawlers moved to an area off southwest Nova Scotia known as the Roseway Basin. Shrimp catches in this area also could not be sustained and the fishery ended by 1972 (Koeller 2000). In the late 1970s commercial concentrations of shrimp were discovered on the eastern Scotian Shelf. Although shrimp trawl licences were issued, the resource was under-exploited for many years, initially due to market conditions, but later due to by-catches of groundfish under quota management. This problem was solved in the early 1990s with the introduction of the Nørdmore grid, a device which allows most fish to escape capture. As a result, trawl catches increased to the total allowable catch (TAC) of 3,000 mt for the first time in 1994 (Koeller et al. 2006). At the same time

abundance and trawl catch rates also increased, indicating the possibility of additional fishing capacity and licenses.

In the early 1990s Mike Newell traveled to New England to research the shrimp trap fishery there. He realized that biological and oceanographic conditions off Canso could be similar to those in Maine where a winter, coastal trap fishery had been conducted since 1971, apparently facilitated by a fall-winter inshore migration of larger shrimp, especially egg-bearing females (Schick 1982). A new inshore fishery would help alleviate the economic hardships, particularly acute in Canso, caused by the groundfish fisheries closures. By 1996 he had demonstrated the economic viability and sustainability of shrimp trapping off Canso, resulting in the issuance of permanent trap licences.

Under co-operative government-industry scientific monitoring and management, the shrimp trawl and trap fisheries on the eastern Scotian Shelf appear to be sustainable under the present management and oceanographic regimes. Abundance has remained high and in 2006 commercial trawler catch rates were the highest recorded (Koeller et al. 2006). Since ~95% of the shrimp TAC is taken by trawlers, most of the scientific and managerial effort has been associated with this sector, as described in Research Documents of the Canadian Science Advisory Secretariat (http://www.dfo-mpo.gc.ca/csas/csas/Publications/Pub_Index_e.htm). This paper attempts to balance the scientific record to some degree by using data collected by trap fishers to describe their fishery. In particular, it describes the biological and environmental characteristics of the areas of successful shrimp trapping in Nova Scotia. It is hoped that this will help in the planning and conduct of future exploratory shrimp trapping projects, and increase their chances of success.

METHODS

Trap data, including fishing location, depth, number of traps fished and catch weight were recorded on official shrimp trap monitoring documents issued by the Department of Fisheries and Oceans to all fishers holding experimental or permanent shrimp trap licences. Monitoring document completion and submission is mandatory for all shrimp fishers and conditional to licensing. These data were accessed from the Maritimes Fisheries Information System (MARFIS), a confidential computer database maintained by DFO. A number of fishers holding experimental licences were issued continuously recording data loggers (AMIRIX Systems Inc. http://www.vemco.com/) to determine temperature at fishing depth. These were attached to one or several traps and periodically downloaded and re-deployed. Experimental fishers also recorded additional information such as per-trap catch weights (instead of per-string as normally recorded) and bycatch information. Samples of shrimp, generally about 4kg and ~500 shrimp) were collected, frozen and returned to the laboratory to determine the biological characteristics of the catch. This information is on the DFO Science Branch Virtual Data Centre

(VDC) and is available to DFO researchers and other interested parties on request. The shrimp database is described in Hunter & Koeller (1997).

All fishers in the experimental and commercial phases of the trap fishery used the modified Maine trap specified in experimental and commercial licence conditions (Koeller et al. 1995), (Fig 1). Crab excluder devices (entrance size restricted to exclude most crabs but allow shrimp to enter) were used in areas where crab bycatch was a problem, e.g. off Canso because small female snow crabs prevent shrimp from entering traps. In general traps are deployed in strings of 5-10 traps, with 10 traps being the most common. Bait usually consisted of salted herring or mackerel, often rotted and macerated to facilitate spread of the attractive scent plume. It is necessary to hang the small-meshed bait bag so that it partly protrudes from the entrance (Figs 1, 2) – bait placed entirely inside the trap usually results in few or no shrimp caught. Observations by Mike Newell and Peter Koeller from Department of National Defense submersibles Pisces and SDL-1 off Canso and Louisbourg in 1995 and 1996 showed that shrimp enter traps slowly, first testing the bait bag at the entrance, then working their way along it into the trap as they feed (Fig 2).

Additional information on shrimp distribution and biological characteristics on the Scotian Shelf is available from several other sources, including groundfish, shrimp and crab surveys using trawls with small mesh liners that retain shrimp. All data sources used in the paper are detailed in Table 1 and are readily available to researchers.

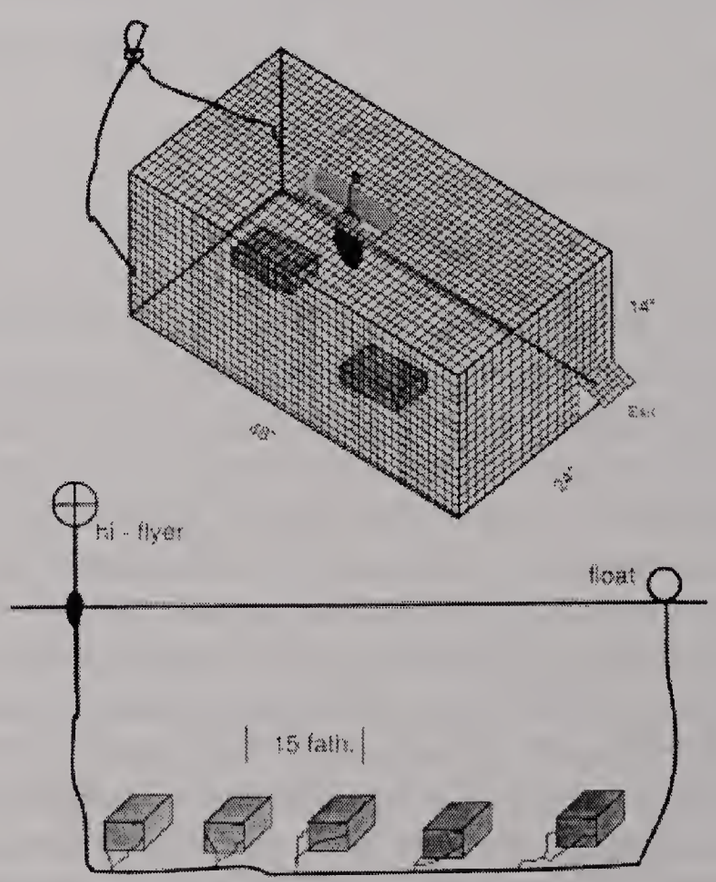

Fig 1. Modified Maine shrimp trap made of 1 x 0.5 inch plastic-coated wire mesh. The drawing also shows the fishing and baiting method (bait bag protruding from trap entrance). Concrete blocks are used for ballast, and a trap door in one corner is used to shake out trapped shrimp.

Table 1 Shrimp catch and biological data sources used in this report. The time spans refer to the dates when shrimp data was available and not necessarily the time span of the entire series. For example, the groundfish survey series began in 1974, but shrimp data was not collected quantitatively until 1999.

SOURCE	DATA ACCESSED	LOCATION	TIME SPAN
Commercial shrimp trap logs	catch weight, location, depth, no. traps, date fished	MARFIS	1995-2005
Commercial shrimp trawl logs	catch weight, location, depth, hours, date fished	MARFIS	1993-2006
Commercial (trap and trawl) and trawl survey catch samples	carapace length, indiv. weight, sex, life history stage	VDC	1995-2006
DFO-industry shrimp trawl survey	shrimp catch weight, location bottom temperature		
DFO groundfish trawl survey	shrimp catch weight, location bottom temperature	VDC	1999-2006
DFO-industry crab trawl survey	shrimp catch weight, location	VDC	2003-2005

Detailed information on the biological characteristics of shrimp sampled (~500 shrimp/sample) during all trapping and trawling operations (survey, experimental and commercial fishing) included: carapace lengths to the nearest 0.1 mm, individual weight to the nearest 0.01 gm, sex and reproductive development stage. The latter included identification of individuals as transitional (in the process of changing sex from male to female), primiparous females (about to spawn for the first time), multiparous females (spawned at least once before) and ovigerous females (eggs on the abdomen). Primiparous and multiparous females are distinguished by the presence or absence of sternal spines, which are lost on first spawning.

Fig 2. Video grab from footage taken aboard the DND submersible SDL-1 in 1996, in the Louisbourg Hole east of Cape Breton Island (depth ~ 200m). Two shrimp are inspecting one end of the bait bag protruding from the entrance. Both shrimp subsequently worked their way along the bait bag into the trap. The taper of the entrance flanges prevents escape. Note that this trap was placed on its side for observation.

Samples were collected bi-weekly during experimental trapping, less frequently (~monthly) during commercial trapping. They are collected from all survey catches and from a temporally and spatially representative portion of the trawl fishery. Shrimp stage length statistics were calculated as described in Koeller (2006).

Surficial geology charts published by the Geological Survey of Canada, Department of Energy, Mines and Resources were used to characterize the ocean bottom on the Scotian Shelf and Bay of Fundy, particularly the location of the muddy clay preferred by *P. borealis* (e.g. Fader 1991).

RESULTS AND DISCUSSION

Shrimp trapping and distribution of the resource

Figure 3 plots successful shrimp catches from experimental and commercial shrimp trap logbooks (green circles, 1995-2005), and from DFO groundfish surveys (blue circles, 1999-2006). This figure also shows the location of null trap (red circles) and trawl (open blue circles) sets (i.e. zero shrimp catches) and so can be used to determine the overall distribution of shrimp concentrations on the Scotian Shelf and Bay of Fundy, as well as the locations where shrimp were trapped successfully. Most notable are the large commercially fished (by trawlers) concentrations of shrimp on the eastern Scotian Shelf. These are found both in the deep (>200m) offshore shrimp holes (e.g. Whitehead, Misaine and Louisbourg, Fig 3) and

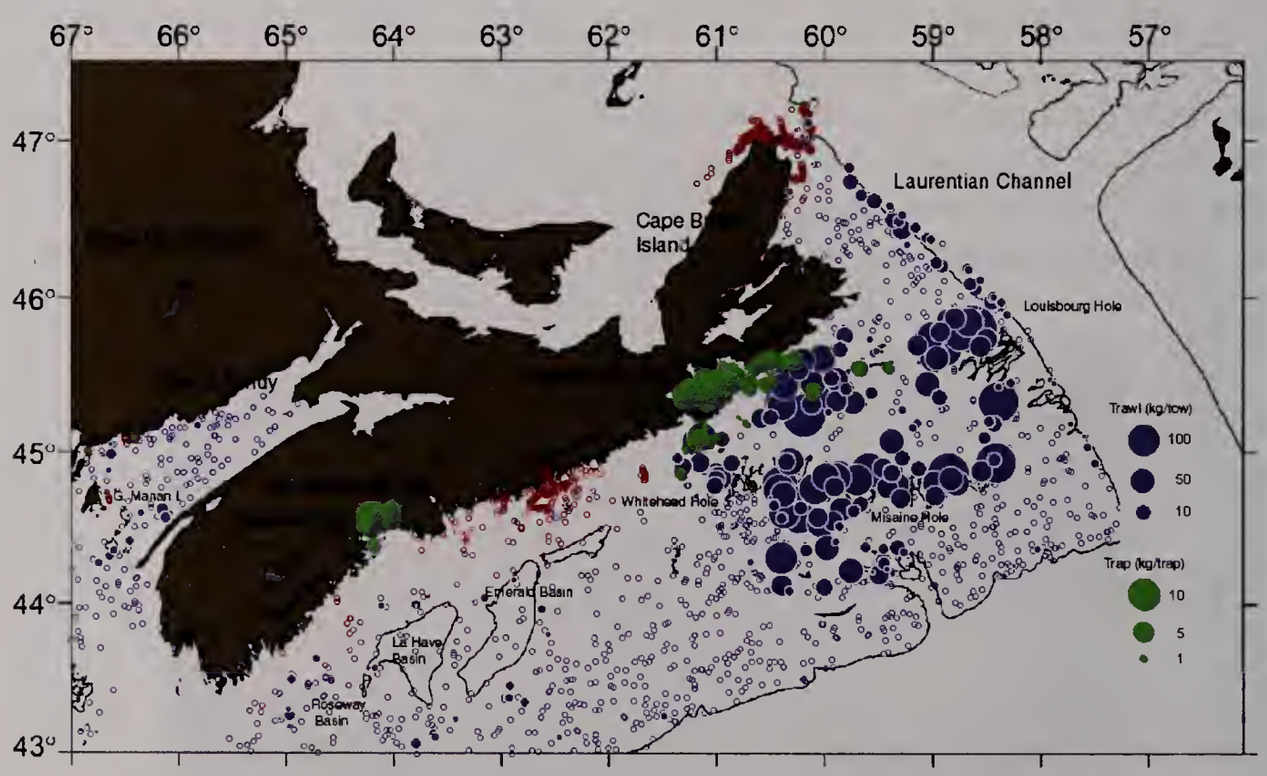

Fig 3. Cumulative catches of Pandalus from experimental and commercial shrimp trap logbooks (1995-2005, solid green circles), and DFO groundfish surveys (1999-2006 solid blue circles). Locations where no shrimp were caught are shown as open circles (trap – red, trawl – blue). Note that along the eastern and south shores southwest of Tor Bay groundfish surveys do not cover the nearshore (inside the ~100m depth contour) and so are indicative only of offshore shrimp distribution.

an inshore area, known as the "Bad Neighbour" (after a shoal of the same name), running from Chedabucto Bay north-eastward along the shore of Cape Breton Island. This latter area has good "muddy" shrimp bottom habitat, geologically termed La Have clay (Fader 1991), which extends some distance offshore, but is separated from the muddy offshore holes to the south and east by shallower water and harder sandy-gravel bottom (Fig 4). The continuity of shrimp catches by trappers in Chedabucto Bay

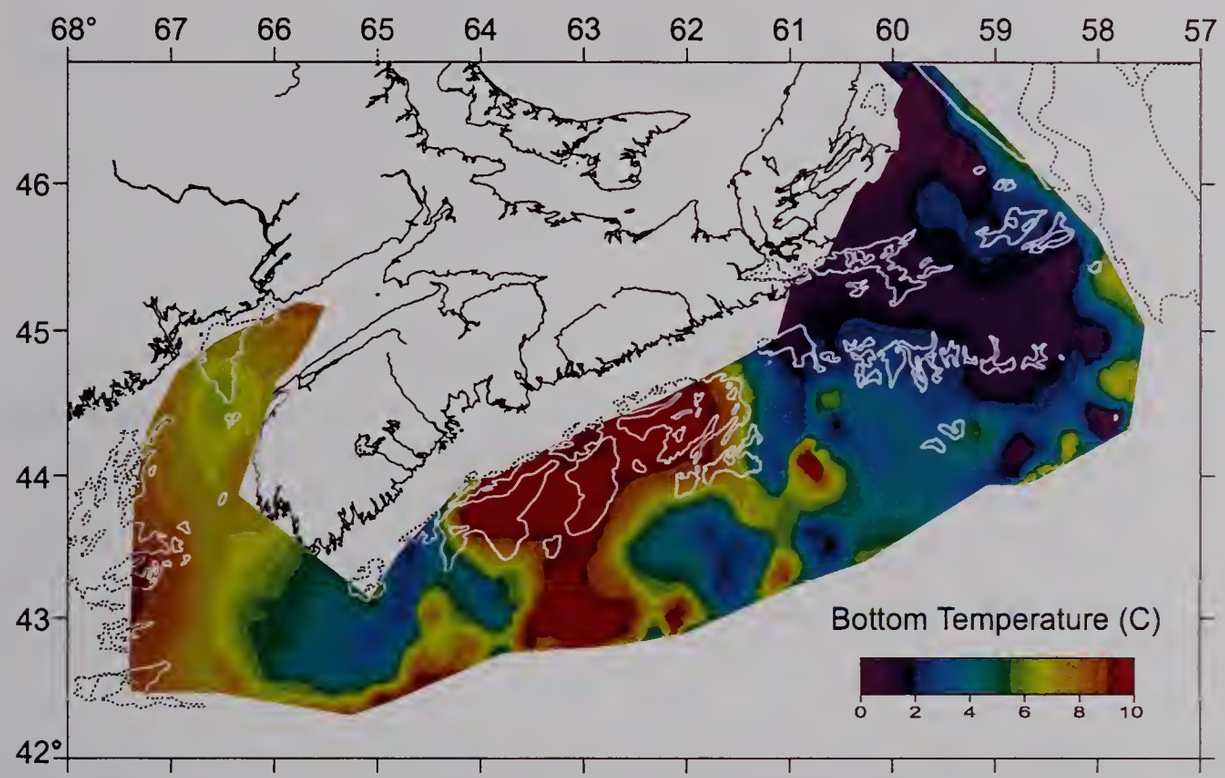

Fig 4. The Scotian Shelf and Bay of Fundy showing the typical large scale distribution of bottom temperatures (e.g. July 1996 groundfish survey), and the distribution of the best shrimp habitat (La Have clay, areas enclosed by white and dotted black lines).

and trawlers in the Bad Neighbour and the continuity of habitat (Figs 3, 4) indicate that the shrimp in these two areas are likely a single population. The relationship between Bad Neighbour shrimp and those in the offshore holes is less clear since the Bad Neighbour and offshore populations are separated by shallower, harder bottom (Fig 4), and both survey and commercial catches (Fig 3) are discontinuous. However, shrimp do move into shallower water during fall-winter (Koeller 2000). This, together with the similarity of their biological characteristics in all areas on the eastern Scotian Shelf (Koeller et al. 2006), suggests that they also constitute a single population. In any case, the success of the trap fishery in Chedabucto Bay appears to be due, at least in part, to the availability of shrimp from the large, adjacent concentration in the Bad Neighbour area.

Figure 5 combines cumulative catch locations from commercial trappers (green stippling) and trawlers (yellow stippling), shrimp catches from shrimp, crab and groundfish surveys (red circles), and the location of the preferred soft mud habitat (light blue shading). Most shrimp trapping occurs at the mouth of Chedabucto Bay at about 100m, over two patches of mud, one

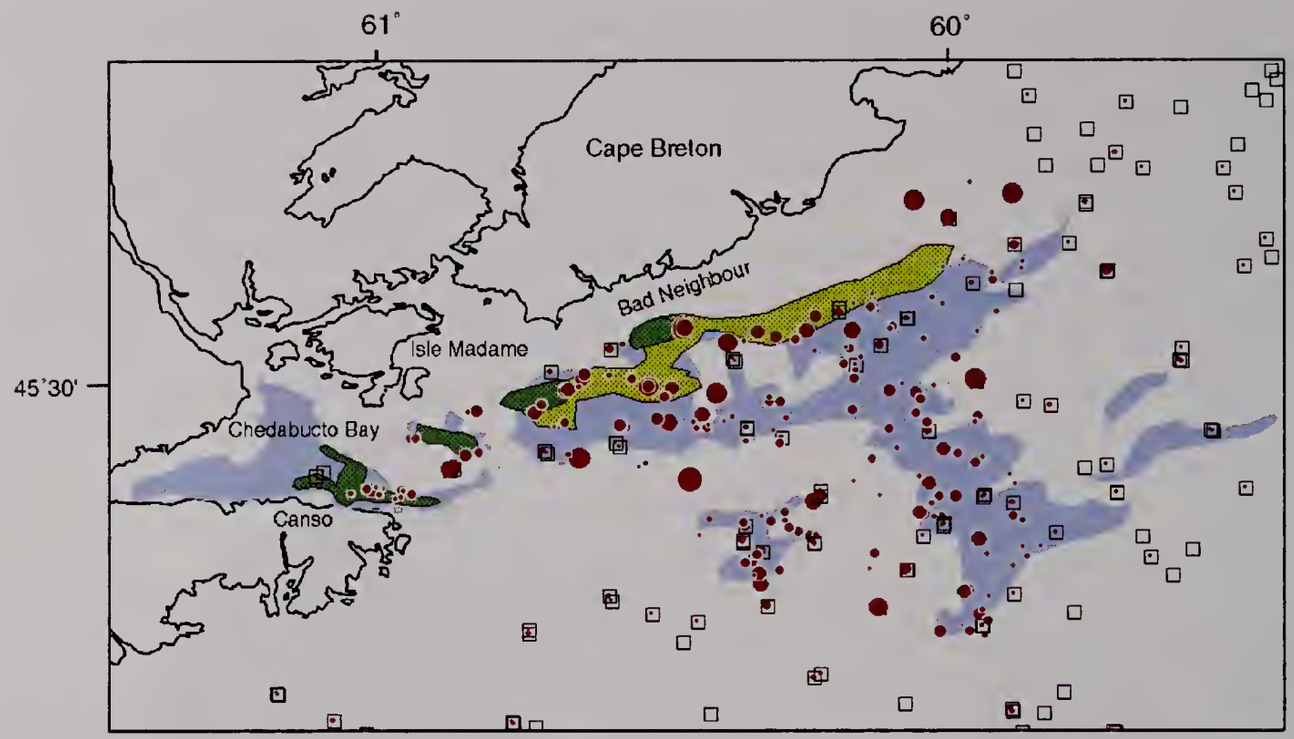

Fig 5. Areas where commercial shrimp trapping (green shading) and trawling (yellow shading) are conducted in Chedabucto Bay and the Bad Neighbour, from log book data. Also shown are cumulative catches of DFO-industry shrimp surveys in June (1995-2006), DFO-industry crab surveys in fall (2004-2005) and DFO groundfish surveys in July (1999-2006) in relative numbers (red circles). Larger circles indicate larger catches, open squares indicate null catches. Shrimp habitat (La Have clay) is shown in light blue.

directly off Canso, the other southeast of Isle Madam. Some trapping also occurs outside the Bay along the Cape Breton shore at the northern edge of the La Have clay, where most of the inshore trawling is conducted. Survey catches show, however, that relatively large quantities of shrimp are found over the soft bottom throughout the Bad Neighbour area, not just in the area nearest to shore where all of the trapping and most of the trawling is conducted. In addition to the extensive shrimp habitat found both inshore and offshore on the eastern Scotian Shelf, temperatures throughout the area are cold compared to the rest of the shelf and within the global preferred range (1-6 °C) of *P. borealis* (Shumway et al. 1985, Fig 4).

The situation is rather different in the area between St. Margaret's Bay and Chedabucto Bay known as the eastern shore (Fig 3). Good shrimp bottom is plentiful in the deep water (>100m) offshore (i.e. in Emerald, La Have Basins), but the water temperatures over these areas are generally above the preferred range (Fig 4). As a result, shrimp are rarely found in these basins. Most of the small embayments along the eastern shore also have fine mud bottoms, but they are quite shallow (<40m, Table 2) and the mud is usually restricted to the bays themselves. Even if shrimp were present offshore, they would be separated from the eastern shore bays by a wide (~20-50 km) strip of harder bottom which runs near shore along mainland Nova Scotia (Fig 4). Trapping along the eastern shore has generally been unsuccessful (red circles, Fig 3), probably because of the

Table 2 Depths of major embayments along the coast of Nova Scotia arranged northeast to southwest. Depths where most trap fishing is conducted are also given.

		Maximum Depth (m)	Fishing Depth (m)
Eastern Shore	Chedabucto Bay	183	100-150
	Tor Bay	40	
	Country Harbour	37	
	Indian Harbour	31	
	Sheet Harbour	26	
	Ship Harbour	18	
	Jeddore Harbour	33	
	Chezzetcook Inlet	5	
	Bedford Basin	70	
	St. Margaret's Bay	84	50-70
South Shore	Mahone Bay	59	40-60
	Medway Harbour	18	
	Liverpool Bay	27	
	Port Mouton	40	
	Port Joli	20	
	Lockport Harbour	15	
	Jordan Bay	33	
	Shelbourne Harbour	26	
	Barrington Bay	20	
	Bay of Fundy	223	

limited amount of suitable habitat in the small embayments, and the lack of an adjacent "feeder" population. However, one experimental trapper successfully caught shrimp at the north-eastern limit of the eastern shore, 10-15 km off Tor Bay, at the northern edge of the Whitehead Hole (Fig 3). This is the closest distance between any of the offshore shrimp holes and the Nova Scotia mainland and is relatively accessible to the small lobster boats used to trap shrimp. It is noteworthy that shrimp were not caught in Tor Bay itself, presumably because they did not cross the harder bottom between it and Whitehead Hole.

Farther to the southwest the situation is different again. Shrimp are trapped successfully in Mahone and St. Margaret's Bays, but there are no large adjacent or offshore populations as in Chedabucto Bay. It is noteworthy, however, that small quantities of shrimp were found offshore in groundfish trawl survey catches, mainly in the Roseway Basin area where the shrimp trawl fishery occurred during the early 1970s (Fig 3). In addition to having La Have clay habitat, Roseway Basin also has the coolest water on the western Scotian Shelf (Fig 4), although it is only marginally within the preferred temperature range, and not during all years (Koeller 2000). The small survey trawl catches offshore are probably remnants of the commercially exploited population which had developed during a more environmentally favourable time period i.e. the colder water temperatures of the mid-to late 1960s (Koeller 2000). It is possible that the shrimp trapped in Mahone and

St. Margaret's Bays also originate from this relic offshore population. As in Chedabucto Bay, the best shrimp trapping occurs in winter (see below under temporal trends). Trap catches tend to increase in the fall, decrease in the spring and are usually poor in the summer, suggesting that shrimp move into these bays during fall-winter, and out of them in the spring-summer, similar to the inshore-offshore migrations reported for the Gulf of Maine population (Shumway et al. 1985, Schick 1982). In the Mahone-St. Margaret's Bay area the small quantities of shrimp found offshore, as well as their long distance (~40 km) from the inshore bays across hard bottom, makes it likely that the seasonal pattern of trap catches here results from relatively short distance movements of a local stock. The shrimp habitat within Mahone and St. Margaret's Bays is somewhat shallower (50-70m) than Chedabucto Bay (100-150m), but considerably deeper than the smaller amounts of muddy bottom found in the small bays and harbours along the eastern and south shores which are generally shallower than 40m (Table 2). In terms of shrimp trapping success, Mahone, St. Margaret's and Chedabucto Bays stand out as being both the largest and deepest embayments along the outer coast of Nova Scotia. It is noteworthy that shrimp trapping has not been attempted in Bedford Basin. Situated near Mahone and St. Margaret's Bays, it has similar depth and habitat characteristics, which may be suitable for a local population of *P. borealis*.

Unsuccessful experimental trapping along the south shore southwest of Mahone Bay suggests that this area is similar to the eastern shore, although the amount of trapping attempted here is limited. A fisher from the south-western end of the area licensed to fish the entire south shore including Mahone Bay continues to station his boat in the Bay during winter for the shrimp fishing because shrimp are unavailable closer to his home port. In the Bay of Fundy, limited experimental trapping yielded a few shrimp, but not in commercial quantities. These shrimp may have come from the relic population, delineated by a few small catches from groundfish surveys, fished commercially during the late 1960s (Fig 3, Koeller 2000). Except for the presence of a large shrimp population and suitably cold water, conditions here seem ideal for inshore shrimp trapping, with good quantities of mud bottom in deep (~180m) water adjacent to the shore of Grand Manan Island. This area may produce a trap fishery in the future, if temperatures decline and a large population develops again.

Extensive experimental trapping off northern Cape Breton failed to catch any shrimp although groundfish surveys show their presence in small numbers relatively close by, along the south-western edge of the Laurentian Channel (Fig 3). Experimental trawling by the fishing industry has also failed to find commercial quantities in the area (Koeller, unpublished data). Although the bottom type is suitable in the Laurentian Channel, temperatures are at or above the upper limit of the preferred range (6°C). The sea bottom at the experimental trapping sites is notably harder, consisting mostly of sand and gravel. In addition, the coast is relatively open, lacks major deeper embayments, and is subject to strong currents which make trapping more difficult, as evidenced by frequently overturned and displaced traps.

Temporal patterns in the trap fishery

The permanent trap fisheries in Chedabucto and Mahone Bays, as well as the experimental fishery in St. Margaret's Bay, are essentially winter fisheries. Chedabucto Bay has tended to have the longest season, extending from late summer-fall to spring, with sharp increases and decreases in catch rates at the beginning and end of the season (Fig 6). The timing

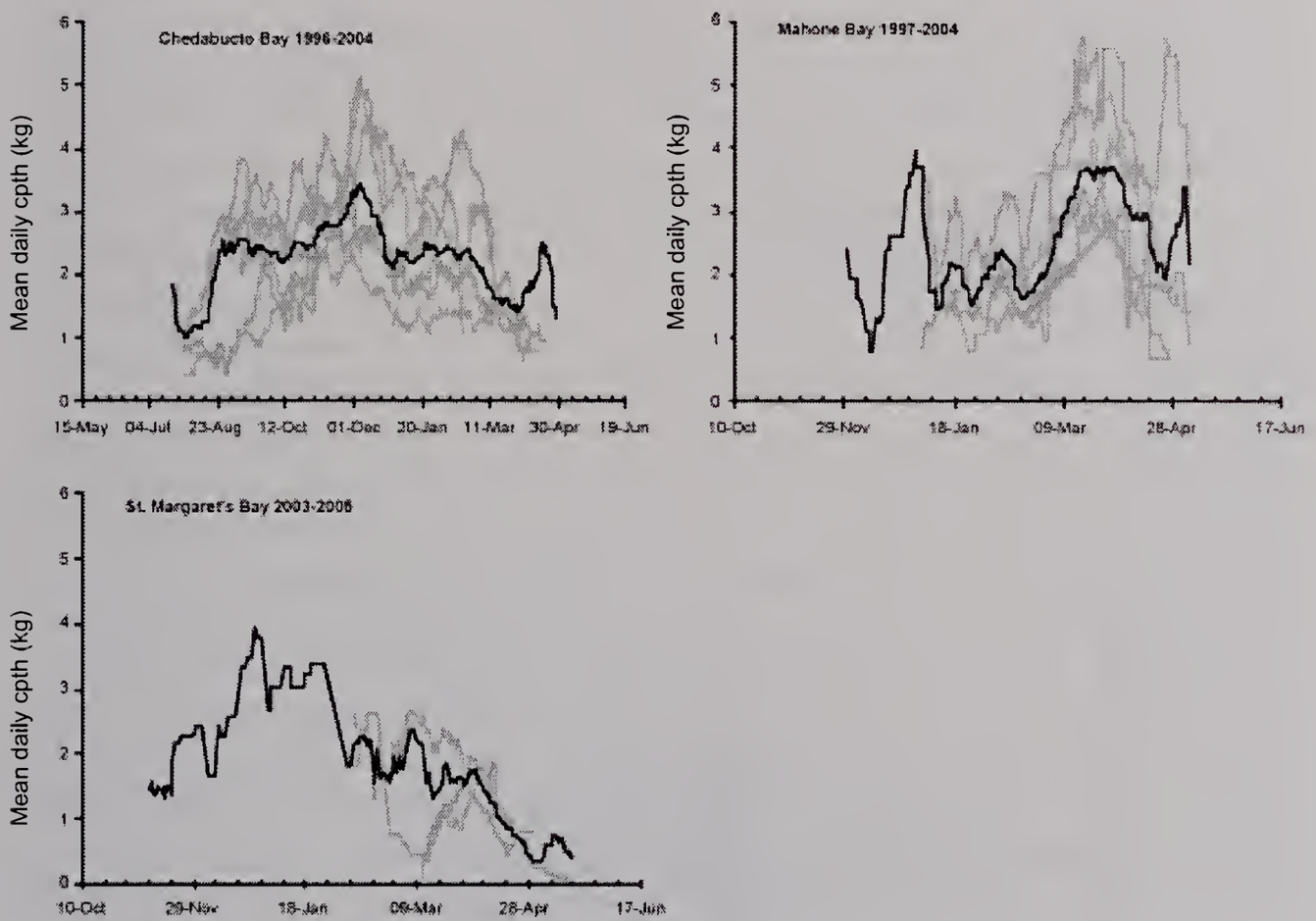

Fig 6. Filtered (9d running mean) daily mean shrimp catch per trap haul from Chedabucto, Mahone and St. Margaret's Bays for the years shown. Shaded lines: daily mean for individual years (not identified by year); solid lines: daily means, all years.

of the increase in catch rates in Chedabucto Bay at the beginning of the season has varied – it has occurred as early as July-August in some years, and not until September in others. Catch rates fluctuated at relatively high levels throughout the season, but there appears to be a decline beginning in December to low levels by the end of April during most years. The pattern appears similar in St. Margaret's Bay, although only limited data are available. The seasonal pattern in Mahone Bay is somewhat different, with a slower increase during most years after the New Year, peak catch rates in March, followed by a relatively rapid decline to the end of April. The seasonality of these patterns could be related to environmental factors, particularly temperatures, which have been shown to influence shrimp abundance and movements (Shumway et al. 1985, Stein 2000).

The seasonal temperature cycles at various depths and locations in Nova Scotia, including temperatures from trap-mounted recorders during

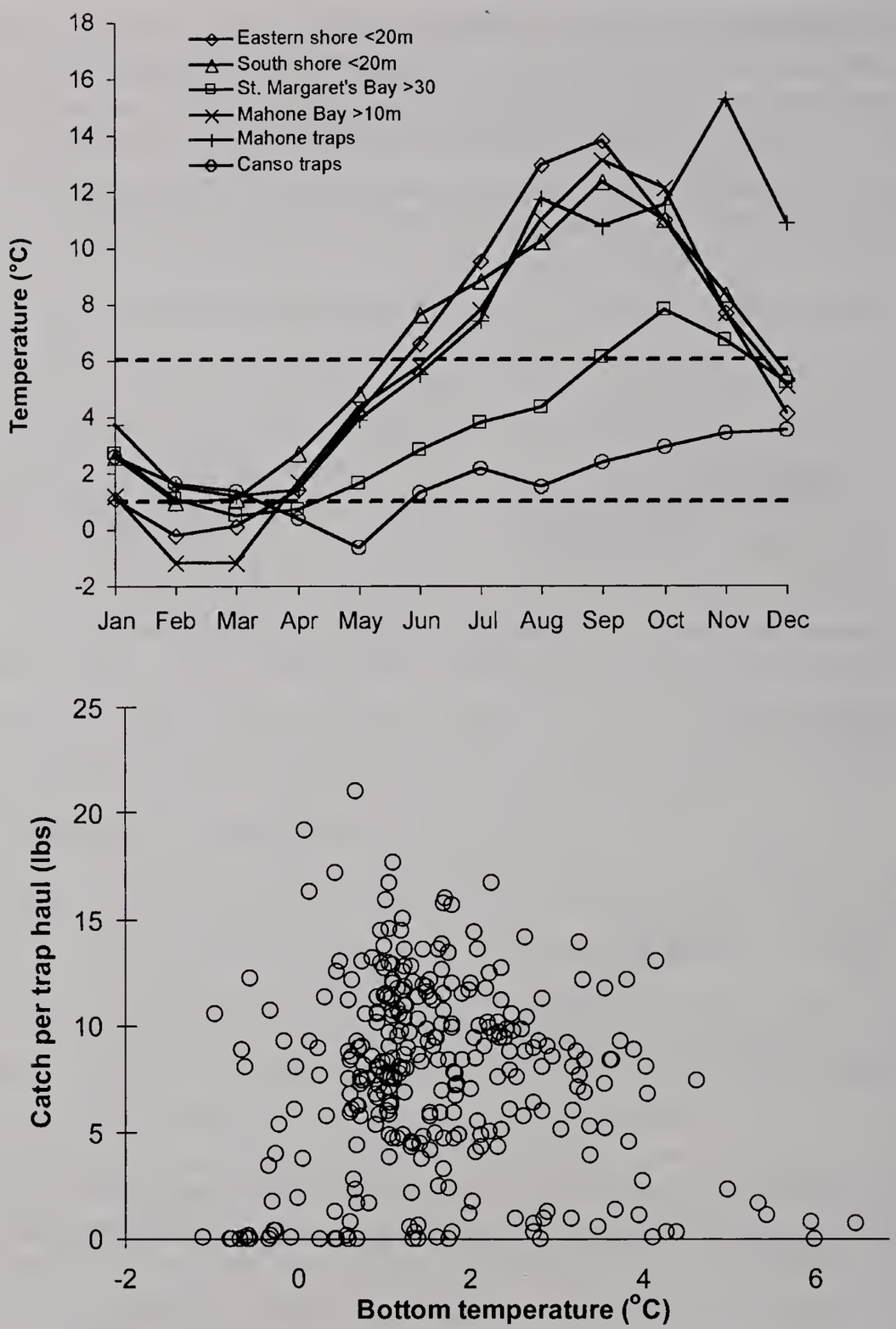

Fig 7. Upper - seasonal temperature (°C) cycle for various areas of interest on the Scotian Shelf. The data were obtained as monthly averages across years at specific depth ranges from the DFO coastal oceanographic database (Gregory 2004) or from continuous temperature recorders attached to shrimp trap during fishing operations. The preferred temperature range of *P. borealis* is also shown (dashed lines). Lower – daily mean catches per trap haul versus daily mean bottom temperatures where both data types were available in Chedabucto Bay 1994-1997.

the fishing season, are shown in Fig 7 (upper), along with the preferred (global) temperature range of *P. borealis*. Available seasonal data along the eastern and south shores are mainly from depths shallower than 20m, however most of the embayments in these areas are this shallow and the temperatures shown are probably representative of the bottom habitat within

most of them. Temperatures along the south and eastern shores fall within the preferred temperature range of *P. borealis* for only 3-4 months of the year (mainly April-June). Temperatures are at or above the lower end of the preferred range in late winter (January-March), and at or above the upper end from summer to early winter (June-December). Combined with limited availability of mud habitat and absence of an offshore feeder population, this may contribute to the apparent lack of shrimp in these areas.

In contrast, the trapping grounds in Chedabucto Bay have temperatures within the preferred range for 9-10 months of the year, from summer to winter (July-February). In addition, extensive favourable habitat and feeder populations are found immediately outside the Bay and farther offshore. The combination of these three factors probably contributes to the success of trapping operations close to Canso. Water temperatures off Canso are generally in the lower half and often near the lower limit of the preferred range. The decrease in shrimp catch rates here begins in December-January when temperatures also begin to decrease. Shrimp catch rates reach their lowest values when water temperatures on the shrimp grounds decrease below the preferred range in April. A plot of catch rates versus bottom temperatures (Fig 7, lower) shows that catch rates decline rapidly below 1°C as expected from the known preferred temperature range. While these data suggest that the appearance and disappearance of shrimp in the Chedabucto Bay trap fishery is related to the seasonal water temperature cycle, it is not clear if this is due to a seasonal migration into and out of the trapping area or to lower activity as shown for lobsters (McCleese & Wilder 1958, Koeller 1999). However, the seasonal cycle of trap catches in Chedabucto Bay and commercial trawling in the Bad Neighbour outside it (Fig 8), as well as survey catches within and immediately outside the Bay

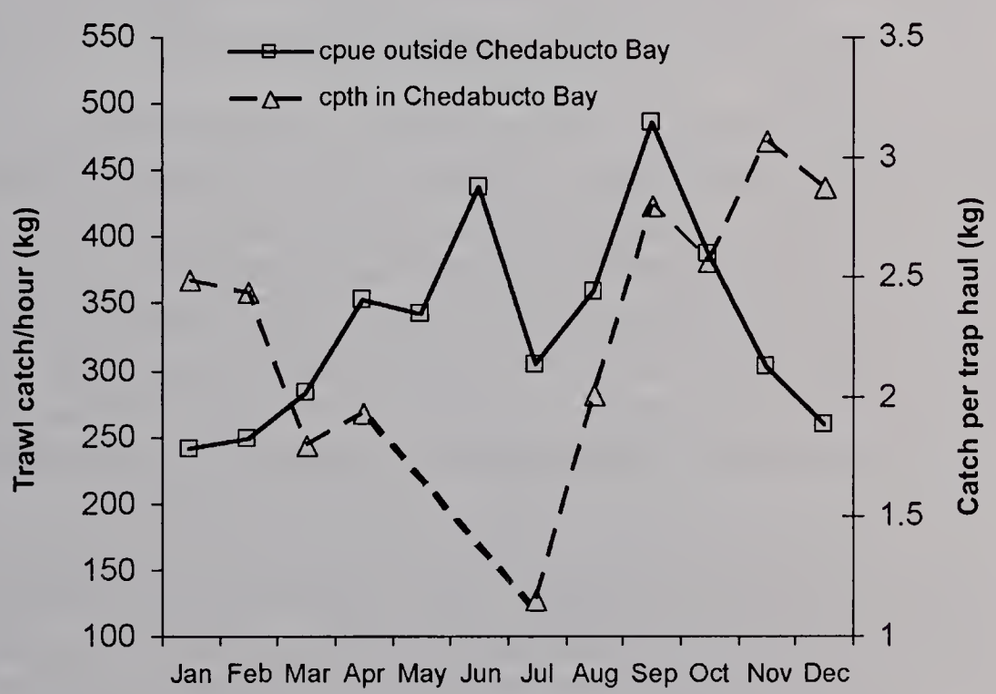

Fig 8. Mean monthly catch per trap haul by shrimp trappers inside Chedabucto Bay (1996-2004) and mean monthly catch per hour by trawlers outside Chedabucto Bay in the Bad Neighbour area.

in June when trap catches in the Bay are usually at their lowest (Koeller et al. 2006), supports a migration from the Bay into the Bad Neighbour in spring, and *vice versa* in fall.

The seasonal pattern of catch rates and temperatures in St. Margaret's Bay is similar to Chedabucto Bay (Figs 6, 7), however, because water is shallower in St. Margaret's Bay, temperatures are more strongly influenced by seasonal heating and tend to be warmer. They are also outside the preferred range for 1-2 months longer than in Chedabucto Bay, and above the preferred range in fall (September-November), which may account for the later start to the fishery in St. Margaret's Bay relative to Chedabucto Bay. Catches decrease in the late winter-spring (February-April) when temperatures dip below the preferred range. The lack of catches during the spring-fall (May-September) period when temperatures are mainly within the preferred range is due to the lack of effort during this period when fishers are otherwise engaged (e.g. the lobster fishery) – shrimp may be present in the Bay and trappable during this period but there are no data to support this.

Mahone Bay is shallower yet than St. Margaret's Bay (Table 2) with depths near or outside those influenced by the previous winter's cold water and strongly influenced by seasonal heating. Consequently, its seasonal temperature profile is similar to the eastern and south shore (Fig 7, upper), with preferred temperatures occurring during short periods in winter (December-January) and spring (April-June). This may partially account for the different pattern of catch rates, including a winter increase that is later than St. Margaret's Bay as temperatures decrease into the preferred range, followed immediately by a decrease in catch rates as temperatures dip below it. As in St. Margaret's Bay, the lack of catches during the period of favourable temperatures during the warming period (April-June) are due to lack of effort while fishers are otherwise engaged and not necessarily to the absence of shrimp.

Daily catch per trap haul data in all areas (Fig 6) show shorter term changes in addition to the seasonal cycles. For example, in Chedebucto Bay during the 1996-1997 season, in addition to the increasing trend throughout the season, the unsmoothed data (Fig 9A) as well as the same data smoothed with a 28-day moving average (Fig 9B), show three peaks in catch rates. This suggests that three "waves" of shrimp entered the Bay during this fishing season. The percentage of females in the catch that were carrying eggs followed the same short term cycles suggesting that these waves were mainly comprised of ovigerous females, a situation analogous to the Gulf of Maine where ovigerous females are reported to migrate inshore during winter to release their eggs (Schick 1982). Spawning (egg extrusion onto the abdomen) occurs only once a year during late summer on the Scotian Shelf (Koeller 1995, 1996a) with hatching in late-winter/spring (March-April), so these waves are not due to spawning events, but rather to a periodic immigration of ovigerous females entering the Bay, or to changes in their catchability.

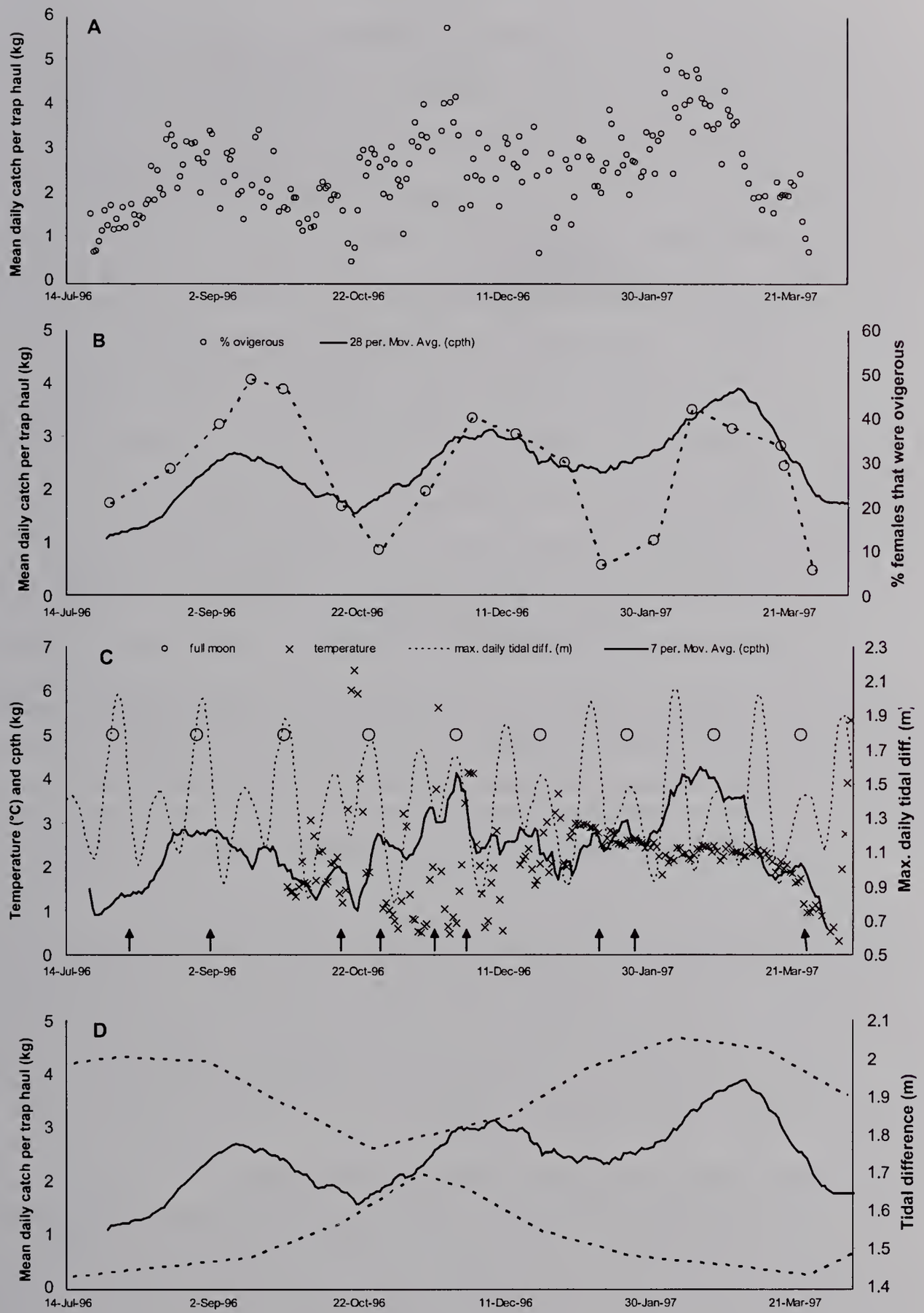

Fig 9. Mean daily catch per trap haul for the 1996-1997 shrimp fishing season in Chedabucto Bay including A. the raw daily means, B. the same data smoothed with a 28d moving average along with the percent of females which were ovigerous in the trap catches (bi-weekly samples), C. Same catch data as above smoothed with a 7-day moving average. Also shown in this panel are mean daily bottom temperatures on the shrimp grounds, the time of the full moon and the tidal cycle, and D. Lower frequency tidal cycle outlined by monthly high-high (upper dashed line) and high-low (lower dashed line) water and the smoothed daily catch per trap haul.

A higher frequency periodicity is also apparent in the same data set when it is smoothed with a seven day moving average (Fig 9C). Some shrimp fishers have indicated that trap catches are related to the lunar cycle, so this figure also shows the time of the full moon and the predicted tidal cycle during the period. Trawl catches of *P. borealis* have been strongly correlated with tidal cycles (Parsons & Sandeman 1981). The higher frequency periodicity does appear to be related to the tidal cycle for at least part of the fishing season, with many of the peaks in catch rates coinciding with tidal peaks. In addition it is known that shrimp orient themselves along currents facing downstream. Observations and underwater photography of Ivanov (1999) and Koeller (1996b) indicate that shrimp behaviour is strongly influenced by water currents including tides. Shrimp are known to undergo diurnal vertical migrations, which will displace them horizontally during the tidal cycle. The amount of this displacement will be proportional to the tidal range, provided that behaviour is otherwise passive. Appropriate modification of diurnal migratory behaviour, such as remaining on the bottom during the ebb, would result in net displacement and increase of the population in an area such as Chedabucto Bay. However, immigration into the Bay is not required to explain the periodic increases in trap catches. During greater tidal ranges more water is transported past any given point such as a trap and more shrimp will come in contact with it and be caught no matter what direction the water is moving. It is also then possible that the lower frequency cycles in trap catch rates (Fig 9A, B) are associated with lower frequency tidal oscillations as suggested by Fig 9D. Water temperatures did not appear to be strongly related to either the high or low frequency changes in catch rates during this fishing season (Fig 9C) although they did appeared to be associated with the drop in catch rates at the end. Note that the large fluctuations in temperatures during the fall-winter period were probably due to storm mixing of a stratified water column. The influence of lunar, tidal and diurnal cycles on the physiology, behaviour, abundance, migrations and catches of marine organisms is a common phenomenon and has been documented for many species, including shrimp (e.g. Parsons & Sandeman 1981, Subramanyam 1965).

Stock relationships and growth of trapped shrimp

The relationship between the length at sex transition (L_t, the length at which males change to females) and the maximum size achieved (L_{max}) has been used to define northern shrimp populations (Skúladóttir & Pétursson 1999). Figure 10 shows that L_t and L_{max} from samples collected in the Gulf of Maine and the Scotian Shelf, including the offshore holes, Bad Neighbour, and Mahone-St. Margaret's Bays, adhere to the invariance rule demonstrated for this species throughout its wide range (Charnov & Skúladóttir 2000, Koeller 2006) i.e. the slope of the regression line, or the ratio of the two variables of a sufficient number of samples, approximates 0.8 (the mean ratio of L_t to L_{max} in the figure = 0.78). Both the Mahone Bay and St. Margaret's Bay samples have L_t and L_{max} values which are significantly shorter ($p<0.0001$)

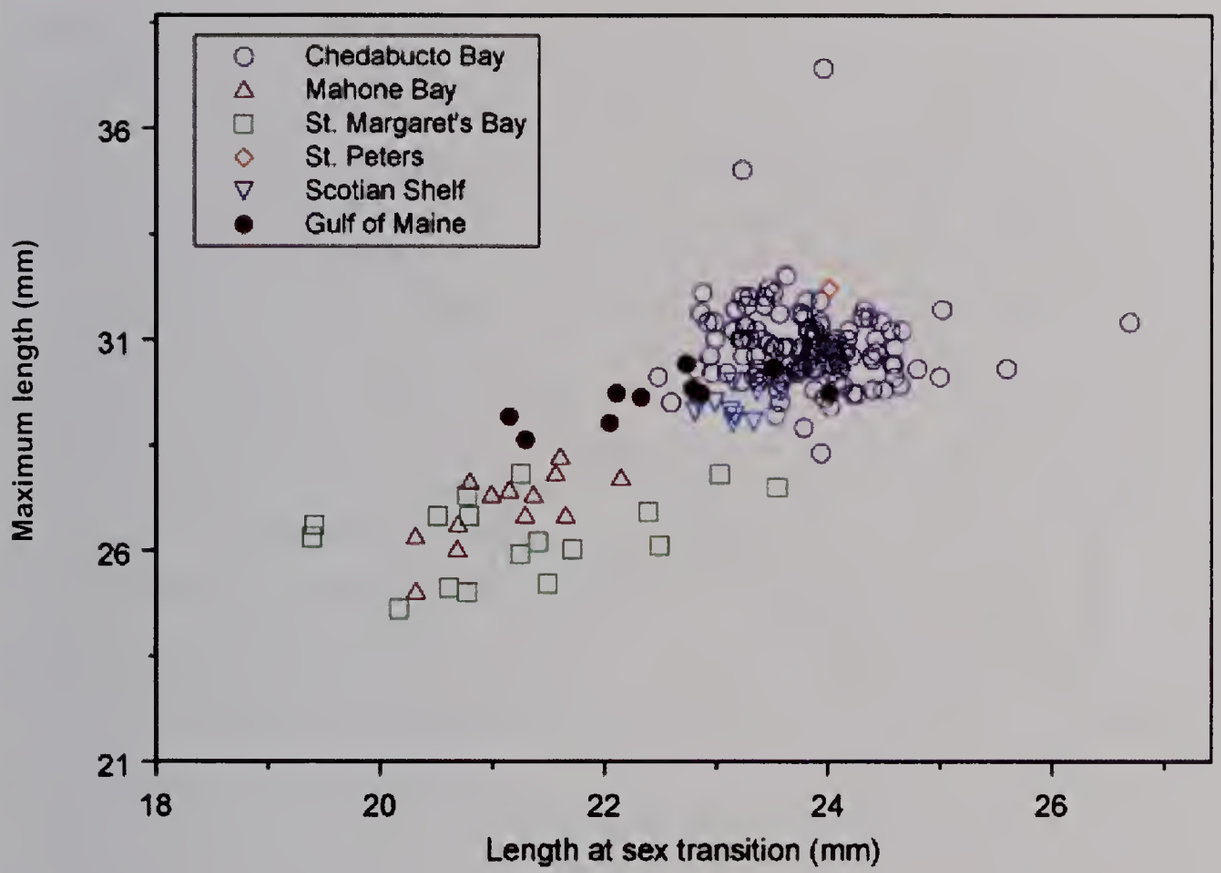

Fig 10. Carapace length at sex transition (L_t) versus maximum size (L_{max}) for individual samples collected by trap in the defined areas. The values for the Scotian Shelf and Gulf of Maine represent annual averages of between 40 and 60 samples collected by research survey trawls. The mean ratio of L_t/L_{max} of these samples and annual averages is 0.78. The single sample marked St. Peter's comes from the north shore of the Chedabucto Bay, samples marked Chedabucto Bay are from the south shore near Canso.

than the shrimp trapped in Chedabucto Bay or trawled on the eastern Scotian Shelf, indicating that they have significantly different growth characteristics (Koeller 2006). In addition to their distance from the shrimp concentrations on the eastern Scotian Shelf and lack of distributional continuity between them, this strongly suggests that the shrimp trapped in Mahone Bay and St. Margaret's Bay constitute a separate population. The L_t and L_{max} values from Mahone Bay are not significantly different from those in St. Margaret's Bay, consequently shrimp trapped in these bays may come from the same local population. Shrimp trapped in Chedabucto Bay, although significantly larger than trawled shrimp on the eastern Scotian Shelf, are closer in size to the latter than any other area. The continuity of shrimp sizes in Chedabucto Bay with those in the Bad Neighbour, which in turn are not significantly different in L_t and L_{max} from the offshore holes, suggests that the shrimp in trapped samples are larger than the trawled shrimp due to selectivity differences between the two gear types, not to differences in growth. They probably belong to the same population managed as a single stock on the eastern Scotian Shelf.

An analysis of all life history stage lengths arranged chronologically (the "stage structure") can be used to infer growth characteristics (Koeller 2006), although this is more difficult if the stage structure is influenced by selectiv-

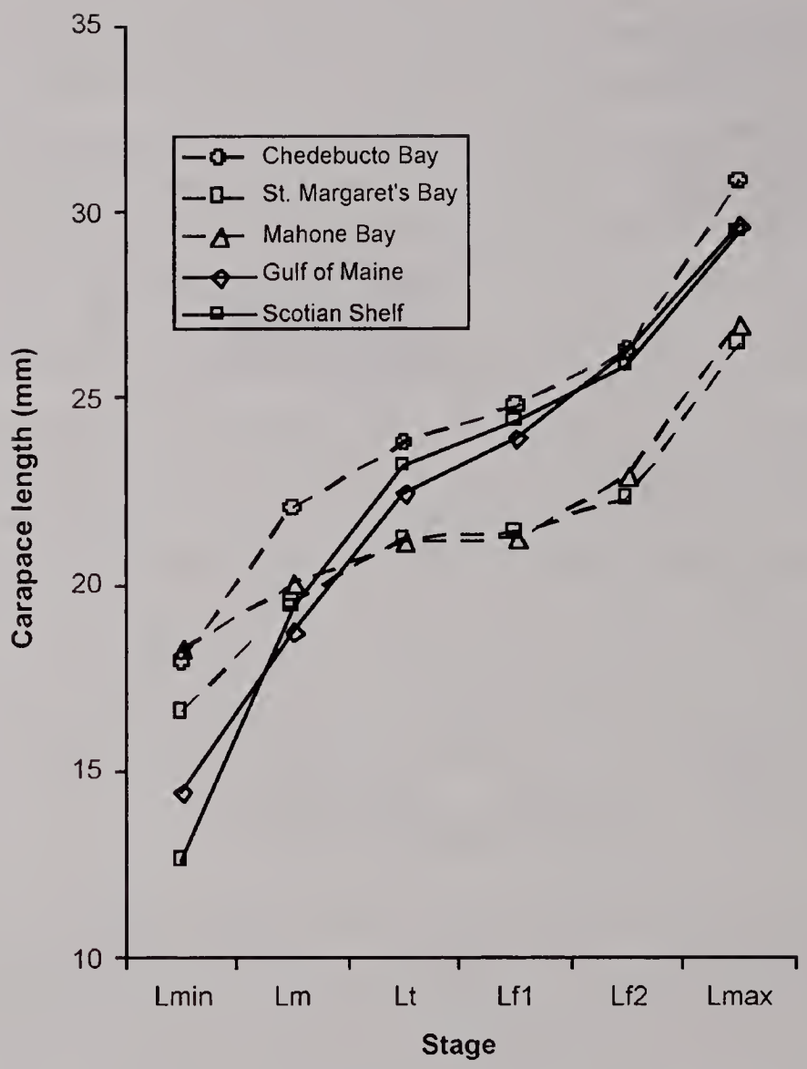

Fig 11. Stage structure for shrimp populations from samples collected by traps (dashed) and research survey trawls from the areas identified. The stage carapace lengths are for L_{min} – mean minimum length in the group of samples, L_m - mean size of males, L_t - mean length at sex change, L_{f1} - mean length of primiparous females, L_{f2} mean length of multiparous females and L_{max} – mean maximum length in the group of samples.

ity factors. However, since all shrimp trapping fisheries require the same trap type and construction under license conditions, comparisons between trapped samples should be valid, as should comparisons between trawl and trapped samples for larger sizes where selectivity for both gear types is near 100%. Figure 11 gives mean stage sizes for trap samples and survey samples from the Scotian Shelf and Gulf of Maine collected over a number of years. The similarity between all stage lengths in Mahone Bay and St. Margaret's Bay, except for the minimum size of shrimp in each sample (L_{min}), further supports the hypothesis that these shrimp come from the same population. The Chedabucto Bay trap sample stage lengths are generally larger than stage lengths from trawl samples on the eastern Scotian Shelf, however, the difference between these areas are greater at the smaller stages and tend to decrease with stage size, supporting the view that the differences are mainly due to differences in selectivity between shrimp traps and trawls. The opposite is the case for trap samples in Chedabucto Bay versus Mahone and St. Margaret's Bays. Most life history stages are clearly larger in Chedabucto Bay trap samples, but the difference between areas

is less for the smaller stages. The generally larger sizes of shrimp stages in Chedabucto Bay trap samples relative to Mahone and St. Margaret's Bays could be due to slower or faster growth, depending on how many male year classes are present. Usually when shrimp grow slower, they spend more time in the male stage, resulting in an additional year(s) of growth and a larger size at transition and subsequent stages. However, in the productive Gulf of Maine the combination of faster metabolic rates due to warmer water temperatures combined with sufficient food availability, results in exceptionally high growth rates and shrimp that are as large as those on the Scotian Shelf which grow much slower (Fig 11, Koeller 2006). This is clearly not the case for shrimp in the Mahone-St. Margaret's area. Except for the smallest stages (L_{min} and L_m) whose sizes are influenced by selectivity differences between gears, all stages in Mahone-St. Margaret's Bay area are smaller than either the Gulf of Maine trawl or the eastern Scotian Shelf trap and trawl samples. For the comparable trapped samples, all stages from St. Margaret's Bay and all but L_{min} from Chedabucto Bay are smaller than trap samples from Chedabucto Bay. It seems likely that these smaller stage sizes result from growth rates that are slower than all other areas throughout their life history. This is plausible considering the variable and marginal conditions experienced by a small inshore population. Unfortunately, the first and second year modes which can be used to determine actual growth rates in the first two years of life are usually not distinguishable in trap samples due to selectivity against smaller shrimp, so this hypothesis cannot be confirmed with the material at hand.

In summary, despite a significant amount of experimental trapping over several years along much of the Nova Scotia coast, in only two areas have permanent trap fisheries been developed - Chedabucto Bay and Mahone Bay - note that the fishery in St. Margaret's Bay was still experimental at the time of writing but also appears to be sustainable. The impression is that successful shrimp trapping along the coast of Nova Scotia by small (~10m) vessels is limited to a few areas with the appropriate combination of physical and biological attributes close to shore. On the eastern Scotian Shelf the availability of suitable habitat, including cold deep water and mud bottom, has allowed the establishment of commercially exploitable, permanent populations both offshore and inshore. Inshore, the shrimp habitat of the Bad Neighbour extends well into Chedabucto Bay and within a mile of Canso, as well as along the shore of Cape Breton. This has allowed small vessels to trap shrimp year round, particularly in winter when catch rates are the highest, probably due to inshore migration of larger, especially ovigerous, shrimp as occurs in Maine. There are currently no major populations offshore from Mahone Bay and St. Margaret's Bay, although these did exist in the past when environmental conditions were more favourable. It is unlikely that the shrimp which appear in these bays during winter originate from this remnant offshore population, since this would entail a lengthy migration over relatively hard bottom. We hypothesise that these shrimp constitute a local population which, driven by the annual temperature cycle, moves into and

out of the inner bay areas where most of the trapping occurs. Mahone and St. Margaret's Bays are generally deeper and much larger in area than the embayments of the eastern and south shores - their extensive mud habitat are more likely to harbour local populations of *P. borealis*.

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REFERENCES

Charnov E, Skúladóttir U (2000) Dimensionless invariants for the optimal size (age) of sex change. Evol Ecol Res 2:1067-1071

Fader GBJ (1991) Surficial geology and physical properties 5: surficial geology. In: East Coast Basin Atlas Series, Scotian Shelf. Atlantic Geosciences Centre, Geological Survey of Canada, Dartmouth, NS

Gregory DN (2004) Coastal Time Series (CTS): A Database of Coastal Temperature Time Series for the Canadian East Coast DFO. Can Sci Advis Sec Res Doc 2004/096

Halliday RG, Koeller PA (1981) A History of Canadian groundfish trawling surveys and data usage in ICNAF Divisions 4TVWX. In: Doubleday WG, Rivard D (eds) Bottom Trawl Surveys. Can Spec Publ Fish Aquat Sci 58

Hunter C, Koeller P (1997) A database for research survey and commercial fishery data on Scotian Shelf shrimp (*Pandalus borealis*). Can Man Rep Fish Aquat Sci 2410

Ivanov B (1999) (VNIRO, V.-Krasnoselskaja 17, Moscow B-140, 107140) Personal communication

Koeller P (1995) Results of the experimental shrimp trap fishery in 1995. DFO (Department of Fisheries & Oceans) Atlantic Fisheries Research Document 96/10

Koeller P (1996a) Aspects of the biology of northern shrimp *Pandalus borealis* on the Scotian Shelf. DFO (Department of Fisheries & Oceans) Atlantic Fisheries Research Document 96/9

Koeller P (1996b) (Bedford Institute of Oceanography, Dartmouth) Unpublished video footage taken from Department of National Defence submersible SDL-1, dives 1071-1075, 1996

Koeller P (1999) Influence of temperature and effort changes on lobster catches at different temporal and spatial scales and its implications for stock assessments. Fish Bull 97:62-72

Koeller PA (2000) Relative importance of abiotic and biotic factors to the management of the northern shrimp (*Pandalus borealis*) fishery on the Scotian Shelf. J Northw Atl Fish Sci 27:21-33

Koeller P (2006) Inferring shrimp (*Pandalus borealis*) growth characteristics from life history stage structure analysis. J Shell Res 25: 595-608

Koeller P, Covey M, King M (2006) An assessment of the eastern Scotian Shelf shrimp stock and fishery for 2005 and outlook to 2006. DFO Can Sci Adv Sec Res Doc 2006/001

Koeller PA, King M, Newell MB, Newell A, Roddick D (1995) An inshore shrimp trap fishery for eastern Nova Scotia? Can Tech Rep Fish Aquat Sci No 2064

McCleese DW, Wilder DG (1958) The activity and catchability of the lobster (*Homarus americanus*) in relation to temperature. J Fish Res Board Canada 15(6):1345-1354

Parsons DG, Sandeman EJ (1981) Groundfish survey techniques as applied to abundance surveys for shrimp. In: Doubleday WG, Rivard R (eds) Bottom trawl surveys. Can Spec Publ Fish Aquat Sci 58

Schick D (1982) The shrimp trap – a better mousetrap? Maine Department of Marine Resources, Fisheries Research Laboratory, West Boothbay Harbour, Maine. Research Reference Document 82/10

Shumway SE, Perkins HC, Schick DF, Stickney AP (1985) Synopsis of biological data on the pink shrimp, *Pandalus borealis* Krøyer, 1838. FAO Fish Synop 144

Skúladóttir U, Pétursson G (1999) Defining populations of northern shrimp, *Pandalus borealis* (Kroyer 1938), in Icelandic waters using the maximum length and maturity ogive. Rit Fiskideildar 16:247-262

Stein M (2000) Hydrographic and atmospheric conditions off east Greenland – their potential effects on the distribution of shrimp (*Pandalus borealis*). J Northw Atl Fish Sci 27:63-67

Subramanyam M (1965) Lunar, diurnal and tidal periodicity in relation to the prawn abundance and migration in the Godavari estuarine systems. Fish Technol 2(1):26–33

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WOODVILLE ICE CAVE (HANTS COUNTY, NOVA SCOTIA) AND NOTES ON THE 'ICE CAVES' OF THE MARITIME PROVINCES

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Several caves and sinkholes where snow and ice persist well into the summer exist in Nova Scotia and New Brunswick. In the past they were sometimes used as a source of ice or for cold storage, and are known locally as 'ice caves' or 'ice holes'. Although they are not true ice caves in the speleological sense of the term because they do not contain perennial ice, they are very similar. Woodville Ice Cave in Hants County, Nova Scotia, described here, is a particularly good example. Invertebrates and bats recorded from such sites are briefly discussed and the possibility of finding psychrophilic fauna in them is suggested.

Plusieurs grottes et dolines sont présentes là où la neige et la glace ne disparaissent que tard durant l'été en Nouvelle-Écosse et au Nouveau-Brunswick. Autrefois, elles étaient parfois utilisées comme sources de glace ou aux fins d'entreposage sous froid. À l'échelle locale, elles sont connues sous le nom de glacières ou de puits de neige. Elles ne sont pas de véritables glacières au sens habituel dans le domaine de la spéléologie parce qu'elles ne contiennent pas de glace pérenne, mais elles sont très semblables. La grotte Woodville (Woodville Ice Cave) dans le comté de Hants (N.-É.) décrite dans le présent document, est un très bon exemple. Nous discutons brièvement des invertébrés et des chauves-souris observés dans de telles grottes et dolines, et nous suggérons qu'il est peut-être possible d'y observer des organismes psychrophiles.

INTRODUCTION

Although many caves in geographical areas where temperatures fall below freezing contain ice during the winter, speleologically the term 'ice cave' is restricted to caves containing permanent ice. Not all ice caves, however, are in areas where there is a glacial climate on the surface: caves with permanent ice can exist in places where the climate is relatively moderate. Examples are known from many parts of the world including the Alps, Pyrenees, elsewhere in Europe and in western Canada.

The anomalous year-round ice and below freezing temperatures in true ice caves occur mainly as a result of the thermo-circulation within the cave. Usually the site has only a single entrance opening leading to a downward-sloping chamber or passage with a seasonal and bi-directional ventilation pattern with air exchange occurring only in winter (Racovitza 2000). Drainage and humidity are also important factors: ice does not survive long where there is liquid water, either as a stream or pond as a result of poor drainage.

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Evaporative cooling in conditions of low relative humidity may be significant in some cases as well as the aspect and shading of the entrance.

There are several natural features in the Maritime Provinces known to local residents variously as 'ice caves', 'ice holes' or by similar terms. Haliburton (1829) mentions "a deep ravine, in which ice may be found throughout the summer: it is known by the name of the 'Natural Ice-House'" near Granville (Annapolis County, NS). Decker (1950) reported a deep gypsum sinkhole near Antigonish, Nova Scotia that "contains ice and snow throughout the summer and used to be used as a meat storehouse before this region received electric power". There is a similar feature in Inverness County, Cape Breton, called the Ice Hole, also said by local informants to have been used for storing meat. It consists of a deep gypsum sinkhole with a shaft at the bottom: ice was observed to be present in July 1971 (Moseley 1976).

In some caves ice persists into the summer; one example is the well-known Frenchman's Cave (Hants County, NS) where ice can be present until early June (Calder & Bleakney 1967). Some of these local caves are also reported to have been used for cold storage and even as a source of ice for making ice cream prior to the widespread availability of domestic electrical power and modern refrigerators. Those referred to locally as 'ice caves' include Woodville Ice Cave and Minasville Ice Cave (Hants County, NS), both in gypsum, and Waterford Ice Cave, a limestone cave in Kings County, NB.

The distinctive landforms known collectively as 'karst' (landscape containing sinkholes, gorges, caves, underground streams, etc.), that develop on gypsum-anhydrite, limestone and other soluble rocks, have been little described in Nova Scotia or New Brunswick. Ice caves are an interesting physical feature of provincial karsts and Woodville Ice Cave in particular is not only of considerable geomorphological and biological interest in itself but is also situated within a fine example of eastern Canadian sulphate (gypsum-anhydrite) karst with large dolines (sinkholes), polygonal karst (i.e. multiple deep sinkholes separated only by narrow ridges) and a dry valley. The cave together with its environs are deserving of protection and preservation.

None of the known local sites are true ice caves, but they are similar in that the physical shape and aspect of the cave produce atypical temperature conditions. Dense, cold air tends to sit in the cave in the spring as ambient temperatures increase whilst in the autumn warm air flows outwards. In consequence, the annual temperature curve is skewed, ice and low temperatures can persist quite late into the summer and the average annual temperature inside the cave is lower than that outside (Moseley 2007a).

DESCRIPTION OF WOODVILLE ICE CAVE

The existence of these 'ice caves' has been briefly noted elsewhere (Moseley 1996, 1998), but none has previously been fully described or mapped.

Woodville Ice Cave (Woodville, Hants County. 45.0341 N. 63.9555 W.), also known as Bear Cave, or locally as 'the ice cave' or 'the cave' (Fig 1), is of particular interest because morphologically and microclimatically it closely resembles a true ice cave. It has a single well shaded east facing entrance situated at the head of a deep steep-sided karst valley, and evidently contained a stream at one time, but is almost dry today. The entrance forms a low arch, approximately 2 m high and 6 m wide. It opens onto a large, sub-circular chamber (20 m x 15 m) with a high ceiling estimated as 12 m at the highest point. The well-drained downward-sloping floor, formed of broken rock with some large boulders, acts as a cold air trap. These are the kind of conditions that produce *bona fide* ice caves elsewhere.

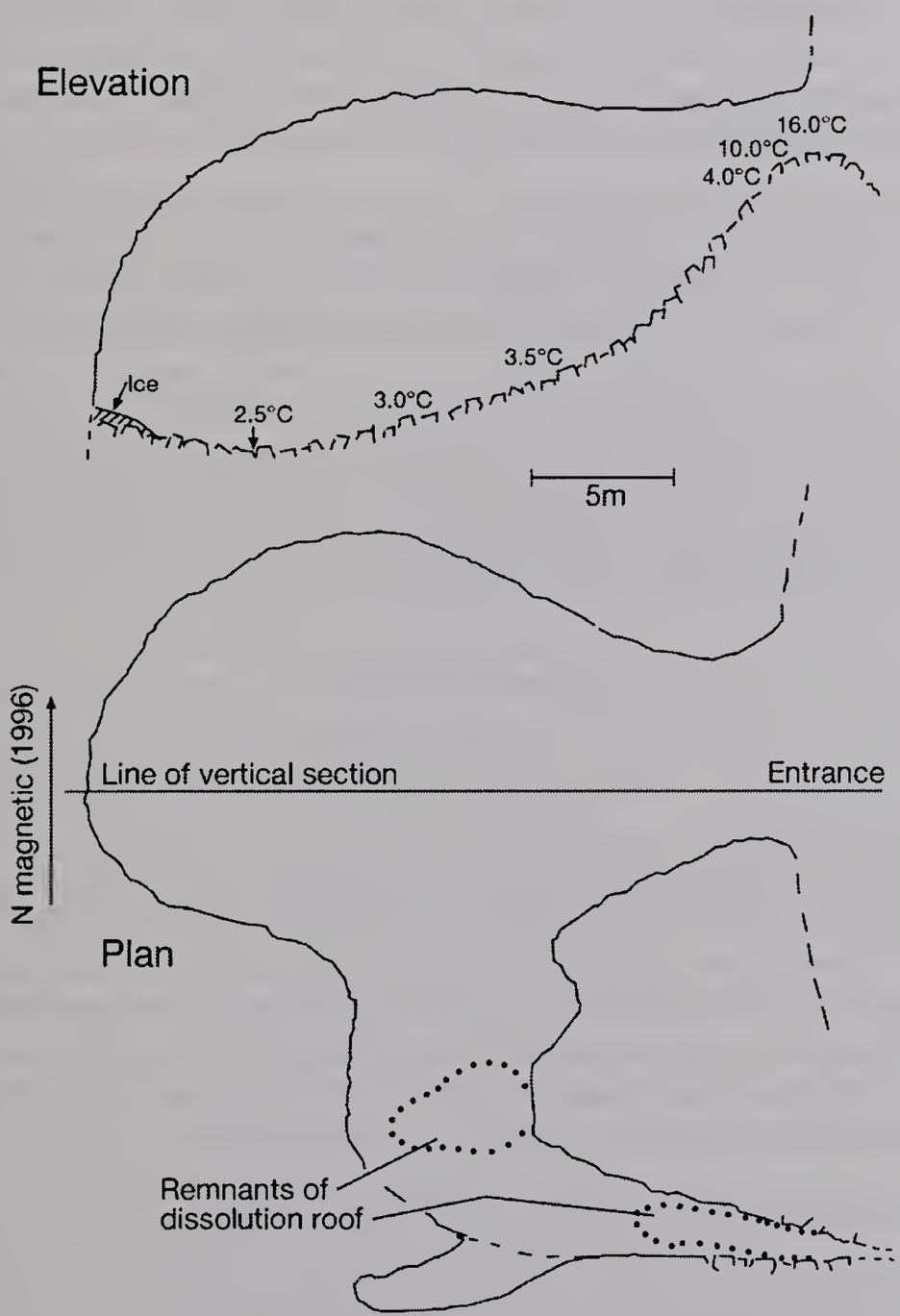

Fig 1. Woodville Ice Cave, Hants County, Nova Scotia. Plan view (Plan) and vertical section along an east-west line through the mid-point of the entrance (Projected Elevation). Survey (Suunto compass and tape): Moseley, Sawatzky and Newberry, 26th April 1996. [Air temperatures measured on 29th July 1997.]

Woodville Ice Cave is a natural dissolution ('solution') cave formed in Mississippian Windsor Group gypsum-anhydrite beds. In terms of its speleogenetic history it is not atypical for an eastern Canadian gypsum cave. Apart from small seeps, there is now no stream in the cave and it is no longer hydrologically active: its present-day physical features are mainly a result of cavern breakdown due to the mechanical weakness of the host rock. Somewhat ironically this is the most stable stage of development of local gypsum caves (Moseley 1996). Extensive blockfall in the chamber has buried the floor, which accordingly is well drained, and there is no remaining trace of the roof formed during the original dissolution. A walking height passage which is probably an old inlet opens off the south side of the chamber, but does not extend very far before becoming sealed by blockfall. Parts of the roof in this passage still retain the original surface. The present-day physical shape of the chamber is a result of partial sealing of the cave mouth by an accumulation of gypsum scree and talus from the roof and the cliff face outside caused mainly by winter freeze-thaw cycles.

Snow and ice which accumulate in the chamber during the winter have been observed to survive until early August: a bank of ice was still present towards the rear, western, wall in the mid-summer of 1997 and the air temperature measured just above the lowest point of the floor was only 2.5°C (Fig 1). By mid-October the ice had melted, and the minimum air temperature had risen to 3.9°C.

Perennial ice may exist deep within the scree and talus that partly closes the entrance. On 6th August 1999, a telethermometer probe (Yellow Springs Instruments) measured a temperature of 0.4°C at a depth of 5cm at a point near the bottom of the talus pile (Hebda 2006). It is interesting to note that if the mean annual temperature at Woodville was as little as 1°C lower, the cave itself might be a true ice cave containing perennial ice (Moseley 1998). As this cave, or similar sites elsewhere, might be sensitive indicators of climate change, it could be worthwhile subjecting them to long term monitoring.

It is speculated that an unexplored cave passage exists leading westward from somewhere below the wall at the end of the chamber; sinkhole topography including an unusually well developed area of polygonal karst continues on the surface in this direction. There may also be inaccessible cave development to the south or east beyond the end of the inlet passage.

Maritime Canadian ice caves and ice holes may be zoogeographically significant because they may harbour psychrophilic invertebrates at the southernmost limit of their range: perhaps even late-glacial relicts. To date collections of invertebrates have been made only in Woodville Ice Cave and Minasville Ice Cave (45.2750 N. 63.8170 W.). The biological fieldwork to establish the presence of psychrophiles has been insufficient, though the presence at Woodville of the springtail *Willemia scandinavia* Stach (Collembola: Poduridae), which has a northerly distribution, is suggestive (Moseley 1998). A list of other invertebrates collected in these caves has been provided by Moseley (2007). Further taxonomic study, especially of

enchytraeid worms (Enchytraeidae), springtails (Collembola), mites (Acari) and fungus gnats (Sciaridae and Mycetophilidae) is desirable.

Because the late summer-early fall cave temperature of *circa* 4°C is significantly lower than that found elsewhere when bats are just entering their hibernation sites, i.e. typically at temperatures greater than 7°C, and the chamber is very exposed experiencing low winter temperatures with a build-up of snow and ice, Woodville Cave is unsuitable for hibernating bats. A single yearling *Myotis lucifugus* seen in the small branch off the inlet passage in October 1996 is thought to have been an inexperienced individual (Hebda 2006). A solitary bat seen in April of the following year (Moseley, 2007b) was assumed to be the same individual.

Minasville Ice Cave (a longer more sheltered cave than Woodville) is a bat hibernaculum housing several hundred *M. lucifugus*. According to Taylor (1997) the two other confirmed local species of cave-hibernating bats (*M. septentrionalis* and *Pipistrellus subflavus*) were also present during winter 1996/97 but only *M. lucifugus* has been found subsequently (Hebda 2006).

Finally, a practical word of caution is necessary. It can be almost impossible to free-climb out of Woodville Cave when there is ice on the scree leading down into the chamber; a rope is essential.

Acknowledgements. I would like to thank the cavers and naturalists who accompanied me and assisted in the field: in particular Dr. D. Sawatzsky and Sean Newberry for their help mapping the Woodville cave. Andrew Hebda (Nova Scotia Museum) read an early draft of the paper and made a number of helpful and useful suggestions. Fieldwork was supported in part by a Nova Scotia Museum Research Grant.

REFERENCES

Calder DR, Bleakney JS (1967) Observations on Frenchman's Cave, Nova Scotia, and its fauna. Nat Speleol Soc Bull 29(1):23–25

Decker RW (1950) A study of the Upper Horton sediments in northern Nova Scotia and Cape Breton Island. NS Department of Mines Annual Report 1949, p 129-167

Haliburton TC (1829) An historical and statistical account of Nova Scotia, in two volumes. Published by Joseph Howe, Halifax, NS

Hebda A (2006) (Nova Scotia Museum, Halifax) Personal communication

Moseley M (1976) Munro Brook Cave, Inverness County, Cape Breton. NS Speleological Society Bulletin No 1, Nova Scotia Museum, Halifax, NS

Moseley M (1996) The Gypsum karsts and caves of the Canadian Maritimes. Cave Karst Sci 23(1):5-16

Moseley M (1998) Invertebrate fauna of Nova Scotia caves. Nova Scotia Museum Curat Report 86:1-37

Moseley M (2007a) Acadian biospeleology: composition and ecology of cave fauna of Nova Scotia and southern New Brunswick, Canada. Int J Speleol 36(1):1-21

Moseley M (2007b) Records of bats (Chiroptera) at caves and mines in Nova Scotia. Nova Scotia Museum Curat Report 99:1-21

Racovitza G (2000) Ice caves in temperate regions. In: Wilkins H, Culver DC, Humphreys WF (eds) Subterranean ecosystems, Vol 30, Ecosystems of the world. Elsevier, Amsterdam, p 561-567

Taylor J (1997) The development of a conservation strategy for the hibernating bats of Nova Scotia. BSc Honours thesis, Biology Dept, Dalhousie University, Halifax, NS. Unpublished data.

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ADDITIONAL RECORDS OF A NON-NATIVE FISH, THE SNOWY GROUPER, (*Epinephelus niveatus*) IN NOVA SCOTIAN WATERS

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At Clam Harbour, Nova Scotia in September 2005, two juvenile Snowy Groupers, *Epinephelus niveatus* (Valenciennes 1828), were captured. Subsequently, in October 2006 during the regular census of six artificial reefs in Sambro Harbour near Halifax, four juvenile Snowy Groupers were observed and one was captured. During the observation period the fish remained close to the reefs and fed voraciously. The arrival of the Snowy Groupers was correlated with the occurrence of a warm Gulf Stream tendril and their disappearance coincided with a drop in water temperature to 7.2°C.

En septembre 2005, deux méroux neigeux juvéniles (*Epinephelus niveatus* – Valenciennes, 1828) ont été capturés à Clam Harbour (Nouvelle-Écosse). En octobre 2006, quatre méroux neigeux juvéniles ont été observés et un autre capturé durant l'inventaire régulier de six récifs artificiels dans le havre Sambro près de Halifax. Durant la période d'observation, les poissons sont demeurés près des récifs et se nourrissaient avec voracité. L'arrivée et le départ des méroux neigeux ont coïncidé avec l'arrivée et le départ d'une masse d'eau chaude amenée par le Gulf Stream (la température de l'eau a chuté jusqu'à 7,2 °C une fois la masse d'eau chaude passée).

INTRODUCTION

Over the past 30 years 69 species from 33 families of non-indigenous fishes have been collected and recorded by the Nova Scotia Natural History Museum, Halifax, Nova Scotia (unpublished data). Both adult and juvenile stages appear in the near shore from July to September; the migrations peak in September.

One species, the Snowy Grouper, *Epinephelus niveatus* (Valenciennes 1828), is particularly noteworthy; it is a member of the family Serranidae (sea basses) (Robins et al. 1991) that consists of 35 genera with 370 species. The sea basses form "a large family of marine fishes, mostly demersal, occurring in tropical, subtropical and temperate seas; in shallow coastal waters and waters of moderate depths to 300 m. Most are inhabitants of

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coral and rocky reefs". Individuals can live up to 25 years; their sizes are quite variable with lengths up to 3 m and weights up to 400 kg. The fish are usually solitary and are mainly hermaphroditic. Four species: Yellowfin Bass, *Anthias nicholsi* (Gilhen & McAllister 1981), Black Sea Bass, *Centropristis striata*, Red Barbier, *Hemanthias vivanus* and the Snowy Grouper, on occasion have strayed into Canadian Atlantic waters (Scott & Scott 1988).

Two adult Snowy Groupers (measuring 76 and 104 cm) were captured in 1978 and 1981 in deep (135 – 185 m) waters of the Scotian Shelf. However, the first record of Snowy Groupers in Atlantic waters is of two juveniles (3 cm) caught in 1928 (Scott & Scott 1988) within 10 km of the present-day observation location. Very little habitat information is available from these records. It is known that during the warmer months, the pelagic larvae can survive and grow outside their normal range if they find suitable habitat (Böhlke & Chaplin 1970).

The normal range for *E. niveatus* runs from southeastern Brazil to Cape Hatteras, North Carolina (Moore & Labisky 1984). Adults are found on the upper continental slope at depths of 240 to 484 m while juveniles inhabit shallower nearshore waters on rock, sand or mud bottoms as well as wrecks and reefs (Matheson & Huntsman 1984, Coad et al. 1995). The juvenile specimens (6-40 cm standard length) are "dark brown with conspicuous white spots in about 11 vertical series and 5 longitudinal rows, usually extending onto head and dorsal fin; caudal and pectoral fins pale yellow with a black saddle blotch on caudal peduncle reaching below the lateral line" (Heemstra & Randall 1993). Adults are distinguished by a coppery gold colour, 18 vertical dark bands on the sides with the rear margin of the caudal fin being straight or concave versus convex in juveniles (Heemstra & Randall 1993).

The recent discovery of the Snowy Groupers occurred during regular biological monitoring of artificial reefs constructed to support faunal and floral abundance and diversity. These artificial reefs are constructed in Atlantic Canada in accordance with regulations under the Oceans Act to mitigate or compensate where marine habitat is damaged or lost through projects such as wharf infilling. In this case rock reefs were used to replace the loss of habitat in Sambro Harbour resulting from an infill to create a wharf.

MATERIALS AND METHODS

Between 14 and 25 August 2006, three rock reef modules were constructed at each of two sites in Sambro Harbour: Cook Head and Inner Sambro Island, near Halifax (Fig 1). The underlying substrate was sand stabilized by *Zostera marina* (eelgrass) at Inner Sambro; at Cook Head the substrate was a sand and mud mixture. The reefs in 10 m of water consisted of 20 numbered rock piles 4 m apart in a 5 by 4 array. Each pile consisted of 270 kg of rocks, graded to a minimum dimension of 15 cm, 1.0-1.2 m diameter, 0.3 m high. The footprint of each array of rock piles was 460 m^2, and 3 ar-

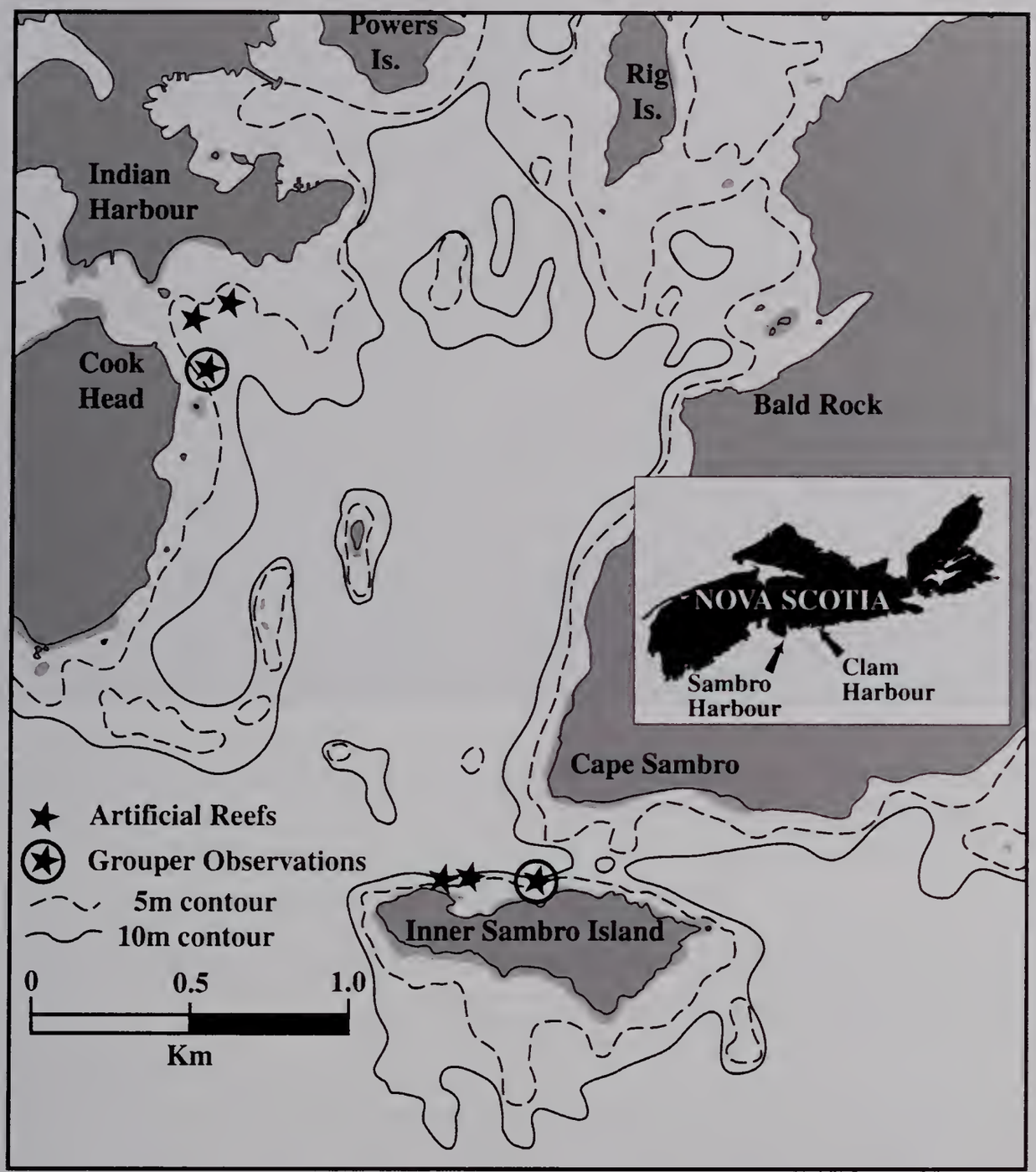

Fig 1. (Inset) Two locations in Nova Scotia where juvenile Snowy Groupers, *Epinephelus niveatus*, were captured in 2005 and 2006. (Large map) Locations of artificial reefs in Sambro Harbour and where Snowy Groupers were observed in 2006.

rays were placed at each site for a total reef area of 2760 m^2. All reef units were in place by August 25, but further rearrangement and disturbance of the habitat continued until September 18.

Following deployment, a weekly inspection of all reefs began on September 25; a diving census of all macrofauna was conducted both in the piles and the surrounding substrate to 1 m beyond the outer boundary of the array. Species were identified *in situ* and no rocks were moved during the census. Bottom temperatures were recorded on each dive with digital thermometers; surface temperatures were available from the ocean data buoy C 44258 Halifax Harbour (MEDS 2006).

Fig 2. A juvenile Snowy Grouper, *Epinephelus niveatus*, captured on an artificial reef near Halifax, NS, Canada 2.5 cm total length

RESULTS AND DISCUSSION

The first Snowy Grouper detected was a 2.5 cm individual on October 3 in a reef at Inner Sambro (Fig 1B). The fish occupied the upper part of the rock pile and moved in and out staying within 10 cm of the opening. On October 20 three fish with similar characteristics and in the same size range were observed at the Cook Head reef module (Fig 1B). Two fish occupied one rock pile and the third was found 6 m away in a second rock pile. On October 24 these three fish were observed in the same numbered rock piles and one was captured alive for identification and measurement. Returning to the same sites November 1, no Snowy Groupers were found on either reef.

Snowy Groupers grow rapidly and at the end of the first year reach 20 cm (Matheson & Huntsman 1984), thus these specimens that ranged in size from 2-3.5 cm were very early juveniles. Interestingly, these fish were observed making repeated feeding attacks on the abundant *Mysis* spp. (Opossum shrimp) around the rock piles. This is consistent with the known behaviour of Snowy Groupers which, because of their usual diet (pelagic fishes, crabs and squid), require the development of very aggressive feeding habits at an early age (Bielsa & Labisky 1987, Coad et al. 1995, Colin et al. 1996).

The temperature on the reefs after their completion on September 25 was 18.1°C, almost the summer maximum. On the first observation of *E. niveatus* (October 3) the temperature was 14.6°C and on the last observation

(October 24) the temperature had dropped to 12.7°C. The following week (November 1) the temperature had dropped to 7.2°C. Not surprisingly, the fish could not be found on the artificial reef and it was presumed that their disappearance was related to this cooling as expatriates frequently die when the water cools significantly (McBride & Able 1998).

Artificial reef habitat in Florida attracted settlement of juvenile *E. niveatus* (2- 10 cm) as a preferred habitat to natural reefs (Arena et al. 2004). The artificial reefs in our study, however, were significantly different in structure from the reef balls and shipwrecks surveyed in Florida (Arena et al. 2004).

Following the observation in the field, one specimen was captured (24 October 2006), retained in an aquarium and identified as *E. niveatus* (Heemstra & Randall 1993). On 19 September 2005, two juvenile Snowy Groupers were collected by snorkelers at Clam Harbour 60 km east of Halifax (and held in captivity overnight). The animals collected by snorkelers and those found in the artificial reef were dark bluish brown with distinctive white dots over the body. The caudal fin was bright yellow (Fig 2).

The morphometrics of the Clam Harbour specimens were:

NSM 88098: Weight (W) 1.78 g; 47.0 mm in Total Length (TL); 36.4 mm Standard Length (S L); 23.2 mm Snout/Vent Length (S/V L); 15.7 mm Head Length (H L); 4.5mm Orbit Diameter (O D); 15.5 mm Pre Dorsal Length (PD L); 15.0 mm Pre Dorsal Depth (PD D); 7.0 mm Greatest Width (G W).

NSM 88099: W 2.06 g; 46.7 mm TL; 36.5 mm S L; 23.5 mm S/V L; 16.4 mm H L; 4.3 mm O D; 15.4 mm PD L; 14.7 mm PD D; 7.0 mm G W.

Dorsal Fin with X spines, 13 rays; Anal Fin with II spines, 10 rays for both specimens.

Although it is not uncommon for the Scotian Shelf of Atlantic Canada to receive exotic species, collections are usually incidental to fishing and lack habitat data. Settlement in the same time frame in two separated reefs (1.9 km apart) suggests transport of a significant number of animals. Eggs of *E. niveatus* are pelagic and their larvae can be entrained by the Gulf Stream and transported north to offshore Atlantic Canada. This is a common route for larval fish transport from the southeast of the United States to the northeast continental shelf (Hare et al. 2002). Warm water meanders between the Gulf Stream and the continental shelf can be the transport mechanism for larval fish into the nearshore (Flierl & Wroblewski 1984). The planktonic egg through larval phase of groupers (Serranidae) requires 30 to 40 days (Colin et al. 1996). If Snowy Grouper eggs were released into the centre of the Gulf Stream the larvae could cover the distance of 1500 km north in about 30 days (Clarke 2006) and the larvae would reach Nova Scotia just as they were completing metamorphosis and would be ready for settlement. On September 3 and on September 20, satellite images (NOAA- 18 Sea Surface Temperature: Sept 03, 2006 1708 GMT and NOAA-17 Sea Surface Temperature: Sept 20, 2006 0252 GMT) (IMCS, 2006) of surface water

temperatures suggest there were meanders from the Gulf Stream that could provide the transport from the main stream to Sambro Harbour. Similarly in 2005, there was a strong influx of warm water into Nova Scotian inshore waters from the Gulf Stream on August 30 to September 3 (NOAA-17 Sea Surface Temperature: Aug 30, 2005 0210 GMT and NOAA-12 Sea Surface Temperature: Sept 03, 2005 0936 GMT) (IMCS, 2006).

September is the optimal month for finding exotic fish species on the Atlantic coast of Nova Scotia. There is no clear evidence, however, for a greater number of arrivals in recent decades. Increasing use of the seashore and greater awareness among the general public of coastal ecology and more intense sub-tidal research may explain the more frequent observations.

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REFERENCES

Arena PT, Quinn TP, Jordan JKB, Sherman RL, Harttung FM, Spieler RE (2004) Presence of juvenile Blackfin Snapper, *Lutjanus buccanella*, and Snowy Grouper, *Epinephelus niveatus*, on shallow-water artificial reefs. Proc Gulf Caribb Fish Inst 55:690-712

Bielsa LM, Labisky RF (1987) Food habits of blueline tilefish, *Caulolatilus microps,* and snowy grouper, *Epinephelus niveatus,* from the lower Florida Keys. Northeast Gulf Sci 9(2):77-87

Böhlke JE, Chaplin CCG (1970) Fishes of the Bahamas and adjacent tropical waters. Academy of Natural Sciences of Philadelphia, Wynnewood, PA

Clarke RA (2006) (Bedford Institute of Oceanography, Dartmouth) Personal communication

Coad BW, Waszczuk H, Labignan I (1995) Encyclopedia of Canadian fishes. Canadian Museum of Nature & Canadian Sportfishing Productions, Waterdown, ON

Colin PL, Koenig CC, Laroche WA (1996) Development from egg to juvenile of the red grouper (*Epinephelus morio*) (Pisces: Serranidae) in the laboratory. In: Arreguín-Sánchez F, Munro JL, Balgos MC, Pauly D (eds) Biology, fisheries and culture of tropical groupers and snappers. International Center for Living Aquatic Resources (ICLARM). Conf Proc No 48, p 399-414

Flierl, GR, Wroblewski JS (1985) The possible influence of warm core Gulf Stream rings upon the shelf water larval fish distribution. Fish Bull 83(3): 313-330

Gilhen J, McAllister DE (1981) First Canadian record of yellowfin bass, *Anthias nicholsi* Firth, taken off Nova Scotia. Proc NS Inst Sci 31:251-254

Hare JA, Churchill JH, Cowen RK, Berger TJ and 5 others (2002) Routes and rates of larval fish transport from the southeast to the northeast United States continental shelf. Limnol Oceanogr 47(6):1774-1789

Heemstra PC, Randall JE (1993) Groupers of the world (Family Serranidae, Subfamily Epinephelinae). An annotated and illustrated catalogue of the grouper, rockcod, hind, coral grouper and lyretail species known to date. FAO Species Catalogue 16

IMCS (Institute of Marine and Coastal Sciences, Rutgers University, New Brunswick, NJ) (2006) IMCS Satellite Images. NOAA Sea Surface Temperatures. Available from <http://marine.rutgers.edu/cool> [accessed 13 December 2006]

Matheson RH III, Huntsman GR (1984) Growth, mortality, and yield-per-recruit models for Speckled Hind and Snowy Grouper from the United States South Atlantic Bight. Trans Am Fish Soc 113:607-616

McBride RS, Able KW (1998) Ecology and fate of butterfly fishes, *Chaetodon* spp., in the temperate, western North Atlantic. Bull Mar Sci 63:401-416

MEDS (Marine Environmental Data Service, Fisheries and Oceans Canada) (2006) Archive Plot. Available from <http://www.meds-sdmm.dfo-mpo.gc.ca/meds/Databases/WAVE/ArchPlot/ArchPlot_Form_e.asp> [accessed 11 December 2006]

Moore CM, Labisky RF (1984) Population parameters of a relatively unexploited stock of Snowy Grouper in the Lower Florida Keys. Trans Am Fish Soc 113:322-329

Robins CR, Bond CE, Brooker JR, Lachner EA, Robert NL, Scott WB (1991) Common and scientific names of fishes from the United States and Canada. Am Fish Soc Special Publication 20

Scott WB, Scott MG (1988) Atlantic fishes of Canada. Can Bull Fish Aquat Sci 219:1-731

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THE NOVA SCOTIAN INSTITUTE OF SCIENCE STUDENT SCIENCE AWARDS 2006

Purpose

To provide an opportunity for students to have their work recognized by a scientific society and to have it considered for publication in a peer-reviewed scientific journal.

Eligibility

The competition is open to any student currently enrolled in a degree program at a recognized educational institution.

Categories and prizes

Undergraduate student

Three broad categories for competition:

Environmental Sciences	e.g. terrestrial ecology, marine biology atmospheric sciences, earth sciences etc.
Life Sciences	e.g. animal and plant cell biology, medical sciences, biochemistry, physiology etc.
Physical Sciences	e.g. physics, chemistry, engineering, mathematics, computer science etc.

Three undergraduate prizes are available in each of these three categories:

1st prize	$200 plus one year's membership to NSIS
2nd prize	$100 plus one year's membership to NSIS
3rd prize	one year's membership to NSIS

Graduate Student

Any discipline
Single prize of $500 plus one year's membership to NSIS

Scientific Writing

For an article written by a student in a non-scientific discipline
Subject must be relevant to science in Nova Scotia
Single prize of $200 plus one year's membership to NSIS

STUDENT SCIENCE AWARDS 2006

The Graduate Student Prize was awarded to:
Timothy J. Fedak
Department of Biology
Dalhousie University
for
"Stomach Stones and Canada's Oldest Dinosaurs"

The Undergraduate Student Prize was awarded to:
Robert G. Harris
Department of Chemistry
Acadia University
for
"Turmeric: Not so spicy after all"

Undergraduate Honourable Mention was awarded to:
M. Jason MacDonald
Department of Chemistry
University of Cape Breton
for
"Evaluation of Phenylalanine Lyase and Peroxidase"

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Volume 44, Part 1, pp. 89-96

2006 NSIS Honourable Mention Undergraduate Student Research Prize Winning Paper

Rhodotorula glutinis: STRAIN ENRICHMENT AND EVALUATION OF PHENYLALANINE AMMONIA LYASE

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The enrichment of a *Rhodotorula glutinis* strain and the determination of its phenylalanine ammonia lyase (E.C.4.3.1.5 – PAL) activity and attempts to measure peroxidase (E.C.1.11.1.7) activity included conventional mycological procedures along with chemical and microscopic examination. Sabouraud-dextrose medium was found to be the most suitable for cell growth, but cells grown on yeast-extract medium exhibited optimal enzyme activity. Growth and PAL activity were measured in yeast cells grown in yeast-extract broth medium for 24-27 h. The appearance of a reddish pink color associated with the yeast cells coincided with the appearance of appreciable PAL activity. The maximum PAL activity and biomass of yeast obtained in the yeast extract medium ranged from 33 to 35 units/mg dry cells and 7.5 to 8.0 g dry cells/L, respectively. In addition to phenylalanine, *Rhodotorula* PAL also used phenylalanine methyl-ester as a substrate. No peroxidase activity was found in these *R. glutinis* cells.

L'enrichissement de la souche de *Rhodotorula glutinis* et la détermination de l'activité de la phénylalanine ammoniac-lyase (E.C.4.3.1.5 – PAL) chez cette souche, de même que les tentatives de mesure de l'activité de la peroxydase (E.C.1.11.1.7), ont compris l'utilisation de procédures mycologiques traditionnelles ainsi que des examens microscopiques et chimiques. Nous avons constaté que la gélose Sabouraud au dextrose est le meilleur milieu pour assurer la croissance cellulaire, mais que l'activité enzymatique est optimale dans les cellules cultivées sur un milieu à base d'extrait de levure. Nous avons mesuré la croissance de cellules de levure cultivées dans un bouillon à base d'extrait de levure pendant 24 à 27 heures et nous avons mesuré l'activité de la PAL dans ces mêmes cellules. L'apparition d'une couleur rose rougeâtre associée aux cellules de levure a coïncidé avec le début d'une période d'activité notable de la PAL. L'activité maximale de la PAL obtenue dans le milieu à base d'extrait de levure a varié de 33 à 35 unités par mg de cellules sèches, tandis que la biomasse de levure maximale obtenue dans le même milieu a varié de 7,5 à 8,0 g de cellules sèches par litre. En plus de la phénylalanine, la PAL de *Rhodotorula* a utilisé l'ester méthylique de la phénylalanine comme substrat. Aucune activité de la peroxydase n'a été observée dans ces cellules de *R. glutinis*.

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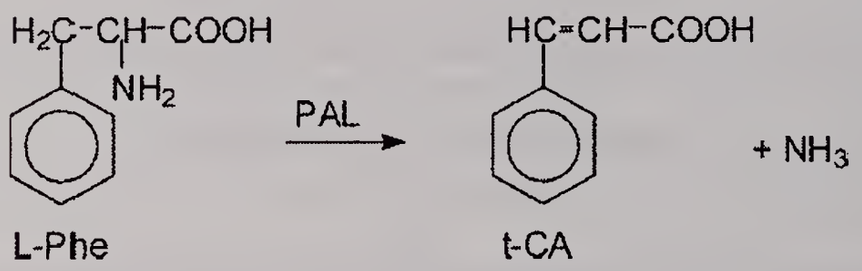
INTRODUCTION

The red basidiomycetes yeast *Rhodotorula* contains a variety of enzymes including phenylalanine ammonia lyase (Koukol & Conn 1961), epoxide hydrolase (Kronenburg et al. 1999), and invertase (Rubio et al. 2002). Phenylalanine ammonia lyase (E.C.4.3.1.5 – PAL) catalyzes the spontaneous non-oxidative deamination of L-phenylalanine (L-Phe) to trans-cinnamic acid (t-CA) and ammonia (Koukol & Conn 1961).



The enzyme is widely distributed in higher plants (Koukol & Conn 1961, Jahnen & Hahlbrock 1988, Whetten & Sederoff 1992), some fungi (Kalghatgi & Subba Rao 1975, Sikora & Marzluff 1982), yeasts (Ogata & Uchiyama 1967, Marusich et al. 1981, Orndorff et al. 1988) and in a single prokaryote, *Streptomyces* (Bezanson et al. 1970). It is, however, absent in true bacteria and animal tissues.

PAL is one of the few non-hydrolytic enzymes that have several commercial applications e.g. treatment of certain mouse neoplastic tumors (Fritz et al. 1976), the quantitative analysis of serum L-Phe in patients with phenylketonuria (Watanabe et al. 1992, Ambrus et al. 1978, Hsia & Holtzmann 1973) and production of L-Phe (Wall & D'Cunha 2006, Yamada et al. 1981, Evans et al. 1986a, b, Hamilton et al. 1985, Evans et al. 1987, Malcolm & Huei-Hsuing 1985, Nelson 1976). Despite its widespread distribution, PAL from *Rhodotorula* yeast has been used exclusively for commercial purposes because of this yeast's high PAL levels and nonfastidious requirements for growth and PAL synthesis (Orndorff et al. 1988, Evans et al. 1987). Peroxidases (E.C.1.11.1.7) are a class of heme-containing enzymes that can be used to reduce hydrogen peroxide while oxidizing a second substrate (Veitch 2004).

Availability of rich enzyme sources is a prerequisite for a biocatalysis in commercial applications. The focus of this paper is to report the results of a study of *Rhodotorula glutinis* strain enrichment and the evaluation of an enzyme of considerable commercial significance: PAL and attempts to detect the presence of peroxidase in this yeast.

MATERIALS AND METHODS

Microorganism

The yeast strain *Rhodotorula glutinis,* RE4607095D used in this study, procured from Oxoid Inc. (Nepean, Ontario) was maintained by weekly

transfers on 3.0% agar plates and slants containing 1.0% peptone, 1.0% yeast extract, and 0.5% NaCl.

Chemicals

L-phenylalanine (L-Phe), L-phenylalanine methyl ester (L-PM), trans-cinnamic acid (t-CA), trans-cinnamyl methyl ester (t-CM), cetyl pyridinium chloride (CPC), tris, guaiacol, hydrogen peroxide, potassium dihydrogen phosphate, and dipotassium hydrogen phosphate were obtained from Fisher Scientific (Fairlawn, NJ, USA). Malt extract, Sabouraud-dextrose medium, yeast extract, peptone and agar were purchased from Oxoid Ltd. (Basingstoke, Hampshire, England). Commonly used chemicals and reagents of highest analytical grade were purchased from commercial sources and used without further treatment.

Preparation of media

Four different media were used in these studies: 1. Malt extract medium (malt extract media powder dissolved in distilled water to give a final concentration of 5.0%) 2. Sabouraud-dextrose medium (Sabouraud-dextrose media powder dissolved in distilled water to give a final concentration of 6.5%), 3. Yeast extract medium (1.0% peptone, 1.0% yeast extract, and 0.5% NaCl) and 4. Minimal salts medium (1.0% $(NH_4)_2SO_4$, 0.5% KH_2PO_4, 0.05% $MgSO_4$, 0.001% $FeSO_4$, 0.001% $MnSO_4$, 0.001% NaCl and 2.0% glucose). For the preparation of slants and plates, 3.0% agar was used. Minimal salts medium prepared with distilled water was the only one of these used in broth form. All glassware and media used in enrichment of the strain were sterilized by steam sterilization, 15 psi and 121 °C for 15 minutes.

Pure cultures on different growth media

R. glutinis yeast cells on culti-loop as obtained from the suppliers were transferred to agar slants containing malt extract medium, Sabouraud-dextrose medium, and yeast extract medium. Cells from three-day old slants were streaked on agar plates of each of the three media. After four days incubation at 37°C, morphological (pigmentation, consistency, opacity, etc.) and microscopic examination of individual colonies appearing on each of the three media was carried out. Cells from plates were inoculated in the broth media containing 1) the malt extract, 2) the Sabouraud-dextrose medium and 3) the yeast extract and minimal salts medium. Growth and PAL activity were monitored after the yeast cells were grown in broth media for 24-27 h.

PAL forward assay

PAL forward activity of *Rhodotorula* yeast whole cells was monitored spectrophotometrically by following the formation of t-CA from L-Phe at an absorbance of 290nm (Herbst & Shemin 1955, Evans et al. 1986b). The reaction mixture (5.0 ml) containing 50.0 mM Tris–HCl buffer (pH 8.5), 37.5 mM L-Phe and 10.0 mg of *R. glutinis* whole cells was incubated at 30 °C

for 10.0 min. The reaction was terminated by inactivating the enzyme with concentrated HCl and separating the cells by centrifugation. The absorbance of the clear supernatant fluid was measured at 290 nm. The reaction mixture to which the substrate was added after termination of the reaction served as the blank. The enzyme activity is expressed by defining one unit of enzyme as the amount required to transform 1.0 nmole of L-Phe/min/mg dry cells at room temperature.

PAL assay using L-phenylalanine methyl ester

The PAL reaction was performed using 37.5 mM L-PM in a 5.0 ml reaction mixture as the substrate instead of L-Phe. The product formed was identified by paper chromatography as follows. At the end of the 10.0 min. PAL incubation period, *R. glutinis* cells were removed by centrifugation (7,500 x g for 5 min). Fifty µl of the clear supernatant fluid along with appropriate standards was spotted on Whatman No.3 paper and developed in a descending system using the organic phase of benzene: acetic acid: water (2:2:1) as the solvent. After the solvent front had traveled 80-85% distance on the paper, the run was stopped and the paper was air-dried. The developed spots in the samples, visible by ultraviolet light, were identified by comparing Rf values with that for the authentic standard. The product of the reaction was quantified by measuring the absorbance of the clear supernatant fluid at 290 nm.

Determination of cell biomass

Growth of *R. glutinis* cells in each of the four media used in this study was compared by measuring the cell biomass. Thirty ml of cultured cells (grown for 24-27 h at room temperature) was centrifuged at 5000 x g for 10 min. The dry weights (45-50ºC) of the cell residues were determined until consistent values were obtained. Cell biomass is reported in terms of g dry weight/L.

Peroxidase assay

The *R. glutinis* cells were examined for peroxidase activities by measuring the oxidation of guaicol at 436nm (Veitch 2004). The reaction mixture (3.18 ml) contained 3.0 ml, 50.0 mM phosphate buffer pH 7.0, 30.0 µl H_2O_2, 50.0 µl guaicol and 100.0 µl enzyme. Initially cells suspended in phosphate buffer were used as the enzyme source and in a later trial, cells suspended in 10.0 ml phosphate buffer containing 100.0 µl cetyl pyridinium chloride were sonicated disrupting all whole cells (using Branson 1510 ultrasonic bath for two 15 minute periods). A reaction mixture excluding the enzyme served as the control.

Data analysis

The values reported are the means of at least three separate determinations.

RESULTS

Rhodotorula yeasts are known to contain high levels of PAL and have non-fastidious requirements for growth and PAL synthesis (Orndorff et al. 1988, Evans et al. 1987). Cells of the *Rhodotorula glutinis* commercial strain were enriched by conventional mycological procedures which included plating of cells on agar medium, selection of colonies followed by culturing them in liquid growth medium. Colonies appeared pink, opaque, circular and had a smooth consistency. Colonies of the yeast cells grown on malt extract medium and Sabouraud-dextrose medium had a glistening texture, while those on yeast extract medium had a dull texture. The colony margin was entire with a slightly raised, convex elevation. Microscopic examination of individual cells revealed gram positive, elliptical cells with an occasionally visible nucleus. Budding was conspicuous in some cells. Cells did not show any appendages such as cilia or flagella. Growth was most abundant on Sabouraud-dextrose agar (Table 1).

Table 1 Growth of *R. glutinis* cells in different broth media

Medium Tested	Dry Weight (g/L)	Standard Deviation
Minimal Salts	1.80	0.11
Yeast-extract	7.82	1.30
Malt-extract	8.97	0.92
Sabouraud-dextrose	*10.21	0.91

R. glutinis cells were harvested in the late log phase (24 – 27 h) of growth for each medium.

A comparison of PAL activity (Fig 1) of the yeast cells in these growth media showed that although Sabouraud-dextrose medium was the most suitable for growth, cells grown on yeast-extract medium exhibited optimal enzyme activity. It was consistently observed that appearance of a reddish pink color during growth coincided with the appearance of PAL activity. The role (if any) of PAL in pigment formation was not investigated further.

Although the yeast enzyme could be shown to use L-PM as a substrate, PAL activity was only about 50% of that obtained when L-Phe was used (Table 2). A chromatographic attempt to quantify the formation of trans-cinnamyl methyl ester (t-CM) from L-PM as a result of the PAL reaction did not produce conclusive results. However, t-CM could be quantified spectrophotometrically using the absorbance values obtained at 290 nm. PAL activity of the yeast cells was found to be 17.2 units. In this case, one

Table 2 PAL activity using different substrates

Substrate	PAL Activity	Standard Deviation
L-Phe	34.0	1.28
L-PM	17.2	1.35

The results reported refer to the PAL activity of cells grown in yeast extract medium.
PAL activity is reported in terms of nmoles of L-Phe or L-PM transformed/min/mg dry cells.

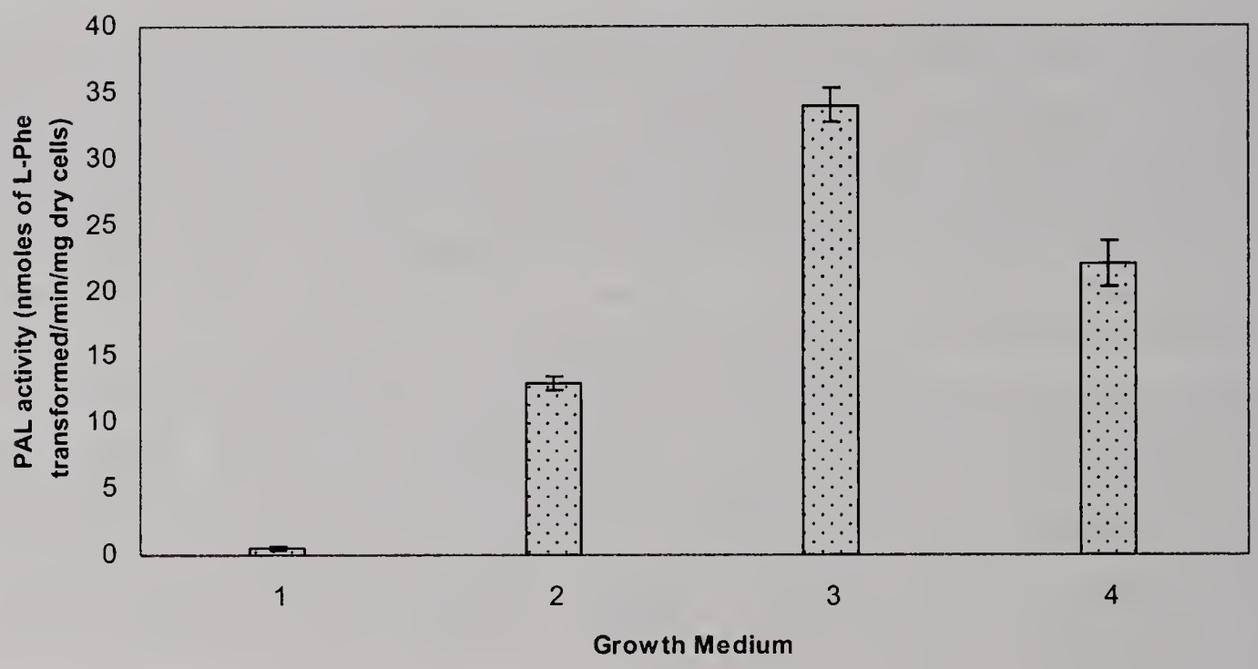


Fig 1 PAL activity of *Rhodotorula glutinis* cells on different growth media: 1. Minimal salts medium (1.0% $(NH_4)_2SO_4$, 0.5% KH_2PO_4, 0.05% $MgSO_4$, 0.001% $FeSO_4$, 0.001% $MnSO_4$, 0.001% NaCl and 2.0% glucose), 2. Malt extract (5.0%), 3. Yeast extract (1.0% peptone, 1.0% yeast extract, and 0.5% NaCl), 4. Sabouraud-dextrose (6.5%).

unit is defined as the amount of enzyme required to transform 1.0 nmole of L-PM/min/mg dry cells at room temperature.

Recently, epoxide hydrolase (Kronenburg et al. 1999) and invertase (Rubio et al. 2002) activity have been demonstrated using *R. glutinis* whole cells. As a spin-off of the main study, the possibility of oxido-reductase (peroxidase) activity in this yeast was tested. The assay did not give any indication of the presence of peroxidase in *Rhodotorula* whole cells or when sonicated cells and CPC treated cells were used as the enzyme source.

DISCUSSION

Biotechnology is increasingly important in the chemical industry. Enzymes are efficient and highly specific catalysts found in living cells and the use of these biocatalysts has dramatically changed many of the chemical processes employed in the pharmaceutical, food processing and chemical manufacturing industries. An important aspect of the biotechnology industry is the enrichment of an organism that produces enzymes of interest and optimization of the conditions for enzyme production by the organism. Although *Rhodotorula* yeast is known to contain high levels of PAL (Evans et al. 1987), there are very few reports on the manipulation of the growth medium of *Rhodotorula* cells to improve enzyme activity (Orndorff et al. 1988). Our study extends earlier work using sonication and various detergents for enriching PAL activity (D'Cunha 2005).

The results obtained indicate that medium composition has a marked effect on growth of the cells and enzyme activity. It is evident from Table 1 that

Sabouraud-dextrose agar supported maximal growth, while yeast-extract medium gave optimal PAL activity (Fig 1). A compilation of PAL activity of different *Rhodotorula* species from earlier work reveals that the enzyme activity varies in the range of 2.0-80.0 units/mg dry cells (D'Cunha 1994). Although not the highest PAL producer, the value of 34.0 units/mg dry cells obtained in this study is higher than most values reported before (D'Cunha 1994). A unique observation was that formation of a pink pigment coincided with the appearance of PAL activity. The role of this pigment in PAL enzyme activity is not known and will be investigated further. The spin-off to detect peroxidase, an enzyme of commercial value, was negative.

Acknowledgements. The authors thank Dr. Michael Tanchak and Mr. Paul MacDougall (Biology Department, Cape Breton University, Sydney, Nova Scotia, Canada) for their kind cooperation. This work was funded by Cape Breton University Office of Academic and Research Institutes.

REFERENCES

Ambrus CM, Ambrus JL, Horwath C, Pederson H, Sharma S, Kant C (1978) Phenylalanine depletion for management of phenylketonuria: use of enzyme reactors with immobilized enzymes. Science 201:837-839

Bezanson GS, Desaty D, Emes AN, Vining LC (1970) Biosynthesis of cinnamic acid and detection of phenylalanine ammonia lyase in *Streptomyces verticillatus*. Can J Microbiol 16:147-151

D'Cunha GB (2005) Enrichment of phenylalanine ammonia lyase activity of *Rhodotorula* yeast. Enz Microbial Technol 36:498-502

D'Cunha GB (1994) Studies on the enzymatic synthesis of fine biochemicals. PhD thesis, Food Technology and Enzyme Engineering Division, BhaBha Atomic Research Centre, Bombay, India

Evans CT, Hanna K, Conrad D, Peterson W, Misawa M (1986a) Production of phenylalanine ammonia lyase: isolation and evaluation of yeast strains suitable for the commercial production of L-phenylalanine. Appl Microbiol Biotechnol 25:406-414

Evans CT, Hanna K, Payne C, Conrad D, Misawa M (1986b) Biotransformation of *trans*-cinnamic acid to L-phenylalanine: optimization of reaction conditions using whole yeast cells. Enzyme Microb Technol 9:417-421

Evans CT, Conrad D, Hanna K, Peterson W, Choma C, Misawa M (1987) Novel stabilization of phenylalanine ammonia lyase (PAL) catalyst during bioconversion of *trans*-cinnamic acid to L-phenylalanine. Appl Microbiol Biotechnol 25:399-405

Fritz RR, Hodgins DS, Abell CW (1976) Phenylalanine ammonia lyase: induction and purification of yeast and clearance in mammals. J Biol Chem 251:4646-4650

Hamilton BK, Hsiao HY, Swann W, Anderson D, Delente J (1985) Manufacture of L-amino acids with bioreactors. Trends Biotechnol 3:64-68

Herbst RM, Shemin D (1955) Synthesis of Phenylalanine from α-acetamino cinnamic acid. In: Blatt AH (ed) Organic synthesis 2. John Wiley & Sons Publishing, New York, p 491-494

Hsia DY, Holtzmann NA (1973) A critical evaluation of Phenylketonuria screening. In: McKusick VA, Claiborne R (eds) Medical genetics. HP Publishing, New York, p 237-244

Jahnen W, Hahlbrock K (1988) Differential regulation and tissue specific distribution of enzymes of phenylpropanoid pathways in developing parsley seedlings. Planta 173:453-458

Kalghatgi KK, Subba Rao PV (1975) Microbial L-phenylalanine ammonia lyase: purification, subunit structure and kinetic properties of enzyme from *Rhizoctoni solani*. Biochem J 149:65-72

Koukol J, Conn EE (1961) Metabolism of aromatic compounds in higher plants, IV, Purification and properties of phenylalanine deaminase of *Horden vulgare*. J Biol Chem 236:2692-2698

Kronenburg N, Mutter M, Visser H, Bont J, Weijers C (1999) Purification of an epoxide hydrolase from *Rhodotorula glutinis*. Biotechnol Lett 21:519-524

Malcolm FAJ, Huei-Hsuing Y (1985) Method for the production of phenylalanine ammonia lyase by fermentation. Genex Corporation (US) European Patent 0,140,714

Marusich WC, Jensen AR, Zamir LO (1981) Induction of L-phenylalanine ammonia lyase during utilization of phenylalanine as a carbon source in *Rhodotorula glutinis*. J Bacteriol 146:1013-1021

Nelson RP (1976) Immobilized microbial cells. Pfizer Inc. (NY, NY) US Patent 3,957,580

Ogata K, Uchiyama K, Yamada H (1967) Metabolism of aromatic amino acid in microorganisms, Part 1: Formation of cinnamic acid from phenylalanine. Agric Biol Chem 31:200-206

Orndorff SA, Constantino N, Stewart D, Durham DR (1988) Strain improvement of *Rhodotorula graminis* for production of a novel L-phenylalanine ammonia lyase. Appl Environ Microbiol 54:996-1002

Oyama K, Irino S, Hagi N (1987) Production of aspartame by immobilized thermoase. In: Methods in enzymology 136, Part C: Immobilized enzymes and cells. Academic Press, New York, NY, p 503-516

Rubio MC, Runco R, Navarro AR (2002) Invertase from a strain of *Rhodotorula glutinis*. Phytochemistry 61:605-609

Sikora LA, Marzluff GA (1982) Regulation of L-phenylalanine ammonia lyase by L-phenylalanine and nitrogen in *Neurosporo crassa*. J Bacteriol 150:1287-1292

Trevan MD, Boffey S, Goulding KH, Stanburg P (1987) Biotechnology: the biological principles. McGraw Hill, New Delhi

Veitch NC (2004) Horseradish peroxidase: a modern view of a classic enzyme. Phytochemistry 65:249-259

Wall MJ, D'Cunha GB (2006) Growth and phenylalanine ammonia lyase activity of *Rhodotorula glutinis*: Optimization of conditions for the synthesis of L-phenylalanine. Proc NS Inst Sci 43 (2): 219-225

Watanabe SK, Hernandez-Velazco G, Iturbe-Chinas F, Lopez-Mungia A (1992) Phenylalanine ammonia lyase from *Sporidiobolus pararoseus* and *Rhodosporidium torulides*: application for phenylalanine and tyrosine deamination. World J Microbiol Biotechnol 8:406-410

Whetten RW, Sederoff RR (1992) Phenylalanine ammonia lyase from loblolly pine. Purification of enzyme and isolation of complementary DNA clones. Plant Physiol 98:380-386

Yamada S, Nabe K, Izuo N, Nakamichi K, Chibata I (1981) Production of L-phenylalanine from trans-cinnamic acid with *R. glutinis* containing phenylalanine ammonia lyase activity. Appl Environ Microbiol 42:773-778

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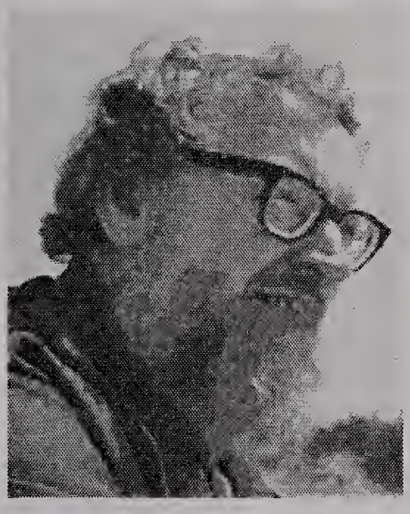
OBITUARY

PETER JOHN WANGERSKY (1928-2007)



Peter John Wangersky passed away on January 7, 2007 at the age of 79 after a brief bout with cancer. His wife, Eleanor, and their three sons were at his side.

Pete was born in Woonsocket, Rhode Island and spent his childhood there and in Lynn, Massachusetts. He entered Brown University at age 16 under a wartime accelerated program, majoring in chemistry. His university career was interrupted by service in the U.S. Army, after which he returned to Brown and completed his degree. After Brown he worked briefly at the Scripps Institution of Oceanography and the U.S. Fish and Wildlife Service. He then went to Yale University for a graduate program, earning his doctorate in zoology under the polymath zoologist G. Evelyn Hutchinson, who probably was the inspiration for his own wide-ranging scientific interests. He taught briefly at the University of Miami, where he met and married Eleanor, and then at the Bingham Oceanographic Laboratory at Yale University. In 1965 he accepted an offer to join the Dalhousie Institute of Oceanography, and was joined there by Gordon Riley, who became the chairman after the retirement of F. Ronald Hayes. Under their leadership the Institute grew and evolved into a full Department of Oceanography. Pete later served two terms as chairman. Pete remained on the Dalhousie faculty until his retirement in 1993 when he and Eleanor moved to Victoria, British Columbia, where Pete accepted an adjunct professorship position at the University of Victoria.

Pete was a very broad and diverse researcher; he was a theoretical ecologist as well as a chemical oceanographer long before either of these 'interdisciplinary' fields became accepted as intellectually respectable. He published in fields as disparate as the organic chemistry of seawater, algal physiology, and mathematical modelling of population dynamics. A paper on lag effects in population cycles, published when he was a graduate student in 1956, is still widely cited. He also held two patents on chemostat design. He loved to go to sea and participated in numerous oceanographic cruises. Pete served as advisor to about 25 PhD students at Dalhousie and was a friend and casual mentor to almost all of the other oceanography graduate students during his tenure. He was known for his breadth, wisdom, willingness to help anyone seeking advice and his warm personality.

Assisted by Eleanor, he helped to create a collegial atmosphere at the Department of Oceanography. Students, staff and friends were all invited to stop by the Wangersky home on Sunday afternoons for coffee, sweets and stimulating conversation. He was a quick and voracious reader with eclectic tastes. His favorite hobbies included photography and fishing.

In 1974 Pete took over as the second editor, from volume 2, of the journal *Marine Chemistry,* initially as a temporary fill-in, and then served as editor-in-chief for the next twenty years. His stewardship of the journal took it from a new, relatively unproven forum, to the well-established authority that it is today. He was noted for encouraging a wide variety of research subjects and new ideas. A special issue of the journal was published in 1997, containing mainly papers based on presentations by former students and close associates at a symposium organized in his honor in 1994.

In retirement he continued on the editorial boards of *Scientia Marina* (Barcelona) and *Environmental Science and Pollution Research,* although he gave up similar duties for *Marine Ecology Progress Series* in 1998. In response to a request from *Limnology and Oceanography* in 1998, he volunteered to help foreign authors with English usage, and received many such calls over the years. He also organized and edited two volumes of The Springer-Verlag series "Handbook of Environmental Chemistry"; *Marine Chemistry* (2000) and *Estuaries* (2006), and served on the advisory board for the series. He was a 50-year member of Sigma Xi. An active member of the Nova Scotian Institute of Science, he served as its President for the 1974/75 term.

Pete was a true pioneer of many disciplines, and his mind remained active and razor-sharp, spinning off more research ideas, spanning many fields, right until his death. Oceanography, marine chemistry, and population ecology have each lost one of their most innovative and productive workers.

His ashes were scattered at sea at Station Papa in the North Pacific on June 11, 2007.

Prepared by Jonathan Sharp, Sifford Pearre, Donald Gordon, Eric Mills and Carl Boyd.

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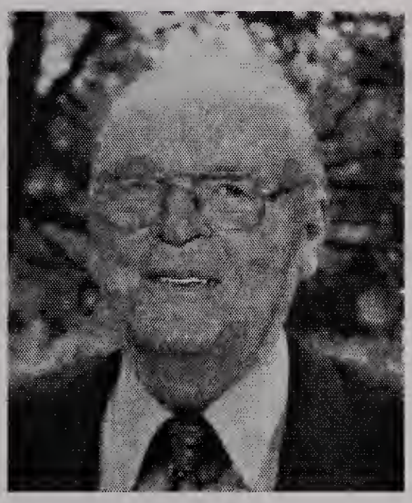
OBITUARY

HARRY CLEVELAND FREEMAN

Scientist, sawmill operator, inventor
Born Greenfield, Queens Co., March 9, 1925
Died Greenfield, April 27, 2007



Acid rain has decimated Nova Scotia's Atlantic salmon fishery and the province is the most heavily impacted area of North America in percentage terms of fish habitat lost. Much of what is now known about the damage acid rain has wreaked on our rivers and streams is a result of research conducted by Harry Freeman and his team of scientists working for the Fisheries and Oceans Department on the 1980s. His work was carried out on the Medway and Westfield Rivers, where he had first observed the movement of salmon as a youth in the 1930s long before the acid-rain threat was discovered. Gloria Sangalang, a research biochemist who worked with Freeman on the salmon project, says theirs was the definitive study that confirmed that acid rain had an impact on the reproductive capacity of Atlantic salmon.

"He was project driven, stubborn in the face of adversity, never shy and would not give up until the job was done", says a former colleague. He felt his greatest scientific achievement was developing sublethal testing procedures on fish while others were concerned only with the lethal effects of toxins. He recognized that healthy fish would disappear if they couldn't reproduce. Freeman's determination and a deep curiosity served him well during the 35 years he spent as a federal government research scientist in Halifax. He wrote, co-wrote and refereed many papers in leading scientific journals and pioneered many laboratory techniques still used today. As a loyal Nova Scotian, he gave his support to many local institutions including life membership in the Nova Scotian Institute of Science.

At 17, he joined the RCAF and, with his strong mechanical skills, won his class gold medal as an aero engine mechanic. He was promoted to crew chief at 19. After his discharge in 1945, he enrolled at Acadia University, where he earned his bachelor's and master's degrees in science. But his family says, "he lived and breathed the forest industry."

He became involved in the family business in 1957, when he helped his father replace the sawmill that had been demolished by floods the previous year in Greenfield, a community synonymous with the Freeman family name since 1832, when Gorham Freeman built a sawmill there. When his father died in 1982, Harry continued to build the business after hours and on weekends, while at the same time carrying out scientific work at a lab

in Halifax. His sons, Charlie and Richard, also joined the business. "He had sawdust in his veins" says his widow, Freda.

Having grown up in the village of Greenfield, he had a lifelong affection for the community. His daughter, Charalyn, says he wanted the children there to have more than he did while growing up. He wanted Greenfield to be able to attract young families to keep the community alive. "Twenty years ago, when the Greenfield Elementary School was closed, Dad worked tirelessly to have it reopened," she said in her eulogy. "He lobbied politicians, purchased textbooks, desks, a school bus and even arranged for teacher, a bus driver and a mechanic." He negotiated to get the community's ball field property and then cleared it, helped build the Greenfield United Baptist Church and recreation centre, the cenotaph, First Settler's Place and sports court.

He had many hobbies, but they almost always involved work, says his daughter. Tree grafting engendered a determination to save traditional Nova Scotian apple varieties by grafting them onto wild trees. "He grafted with a vengeance, both in his own orchard and for others. He once almost missed a flight to Europe because he was busy grafting trees for a friend. His loyal grafting apprentice would proclaim 'the mad grafter strikes again.'" Whether divining for water, restoring antique cars or hitting the bull's eye at the annual Turkey Shoot, Harry succeeded.

When the community turned out for his memorial service, his antique cars were parked outside the Greenfield Baptist Church and the choir sent him off with *You Are My Sunshine*, the song a young Freda was singing when he first set eyes on her.

Prepared by John Soosaar (soosaar@ns.sympatico.ca) from contributions by the Freeman family and colleagues. This obituary (now slightly altered) was printed first in the Halifax Daily News, May 13, 2007.

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NOVA SCOTIAN INSTITUTE OF SCIENCE
SESSION 2005-2006

PRESIDENT'S REPORT

During the past year, members of the Institute have actively engaged in furthering its mandate of promoting science in Nova Scotia. This has been achieved in six ways, by:

- publishing the peer-reviewed Proceedings of the Nova Scotian Institute of Science,
- presenting a program of monthly public lectures by expert Nova Scotian scientists,
- providing financial support for Regional Science Fairs,
- running the annual scientific writing competition,
- running a mentorship program for university science students, and
- developing and actively maintaining the Institutional web site.

For the past several years, the Proceedings have been published under the very able editorship of Dr James E. Stewart who has maintained a high standard. He has been assisted by a dedicated Editorial Board. Jim has informed Council that he wishes to retire in the near future and Council has initiated a process to ensure continuity in this important institutional activity. Council is also aware of changes in the publishing world as the internet becomes more pervasive. The Institute is indebted to Dr Stewart and to members of the Editorial Board for their services.

The Institute sponsored seven public lectures during the past year, all but one of which were held at the Museum of Natural History, which has for some time helped to support Institutional activities. Excellent lectures were given by G. Marangoni (applied chemistry, muds for oil drilling), A. Speers (food science, brewing beer), M. Leonard (biology, communications between birds), S. Murray and A. Guha (pathology, detection and treatment of a virulent form of cervical cancer), C. Watters (computer science, developing improved human interfaces for hand-held computers), R. Côté (environmental studies, integrating industrial and natural ecosystems), D. King (oceanography, developing and marketing biotelemetry systems). The January lecture was held at the University of King's College to which the Institute is indebted for the provision of space.

Attendance at some lectures was disappointingly low. Council has considered the problem, which most likely stemmed from using titles and abstracts supplied directly by the speakers. The seminar coordinator will attempt to develop more publicly attractive titles and abstracts for the next year and Council has run a survey of NSIS members to help determine if seminars are meeting their needs.

Another important activity run under the aegis of the Institute is the financial support given to

Regional Science Fairs in Nova Scotia. This year, the Conseil Scholaire Acadien Provincial and the Mi'kmaq First Nation Boards for the first time sent students to the national science fair and the NSIS provided support to ten science fairs.

The annual Science Writing Competition was organized this year by Ken Adams. An initial flurry of potential entries finally ended with six essays being submitted. Three of these were of a prize-winning calibre, with Robert G. Harris (Acadia University) winning the undergraduate prize, Timothy J. Fedak (Dalhousie University) winning the graduate prize and M. Jason MacDonald (Cape Breton University) receiving an honourable mention in the undergraduate category.

The Mentorship Program, under which younger students are paired with an active research scientist, was continued by Sean Tibbetts. This year, 5 students and 7 mentors have been linked by the program.

The Institute is very fortunate to have the services of an excellent webmaster, John Cordes, who continues to develop the web site so that it not only reflects current activities, but now also has a substantial part devoted to information on the *Proceedings,* as well as historical features of the Institute. A list of past presidents, beginning with the Earl of Musgrave (1862) and the start of a Hall of Fame for distinguished Nova Scotian scientists will no doubt attract the attention of historians. The Institute is indebted to both John Cordes and Past President Carolyn Bird for getting this latter feature on to the web site. Given the explosive growth during the past few years in the dissemination of information over the internet, it is essential that the Institute increase its profile through its website.

In other activities, the Institute co-sponsored, with the Ecology Action Centre, a symposium at St Mary's University on Sable Island and wrote to the Heritage Strategy Task Force of the Voluntary Planning urging continuing support for such science-promoting organizations as the Nova Scotia Museum and the Discovery Centre. Finally, I must thank all members of Council for their diligence and hard work. Special thanks must go to Susan Bjornson who is retiring as Publicity Officer and to Linda Marks who served admirably as Secretary of the Institute.

Respectfully submitted to the AGM
May 1, 2006
J. Stuart Grossert
President NSIS

APPENDIX: MONTHLY LECTURES

October 3: *What's in a name—especially if yours is mud?*
Gerry Marangoni, Department of Chemistry,
St. Francis Xavier University

November 7: *Brewing science: advances and challenges*
Alex Speers, Department of Food Science and
Technology, Dalhousie University

December 5: *Begging birds and the evolution of elaborate animal signals*
Marty Leonard, Department of Biology
Dalhousie University

January 9: *Menopause, aging, atrophy and cancer in the gynaecologic tract*
Shawn Murray and Ashim Guha,
Department of Pathology, Dalhousie University

February 6: *Information on the move: the user perspective*
Carolyn Watters, Faculty of Computer Science,
Dalhousie University

March 6: *Integrating industrial and natural ecosystems: the possibilities*
Ray Côté, School for Resource and Environmental
Studies, Dalhousie University

April 3: *Development of commercial biotelemetry equipment*
Doug Pincock, AMIRIX/VEMCO Systems, Inc.

May 1: *Knife, bronzes and life*
Ivar Mendez, Division of Neurosurgery and
Brain Repair Centre
Queen Elizabeth II Health Sciences Centre
Annual After-Dinner Speaker

LIBRARIAN'S REPORT

There are currently one hundred and eighty-eight NSIS exchange partners. Three institutions cancelled their exchange program with us over the past year; including Royal Botanic Gardens, Kew; Netherlands Institute for Sea Research and Nassauischer Verein fur Naturkunde The number of institutional members remains unchanged from last year and continues to be twenty-seven. Invoices were sent out in February 2006 for institutional memberships and to date we have received payment for eighteen renewals.

In June 2005 Volume 43, Part 1, of the **Proceedings of the *Nova Scotian Institute of Science*** was published. The Library mailed the issue to exchange partners and institutional members. In addition, we also did the mailing to personal members. Postal charges for distribution of the printed journal cost the Institute $1436.00 in 2005.

The ***Flora of Nova Scotia*** by A.E. Roland was reprinted and has a new one-volume format with spiral binding. This title is priced at $35.00, and thirteen of the fifty available copies have been sold. All remaining copies of the former two-volume format of the ***Flora of Nova Scotia*** were sold @$15.00.

Publications continue to be received regularly from our 188 active exchange partners and this material is added on an ongoing basis to the collection. I would like to thank Carol Richardson and the Serials Department staff in the Killam Library who ensure that the NSIS Library operations continue to function smoothly.

Respectfully submitted to the AGM
May 1, 2006
Sharon Longard
Librarian NSIS

EDITOR'S REPORT

The Proceedings of the Nova Scotian Institute of Science Volume 43 Part 1 was published in June 2005. This 75-page issue included three submitted papers, two prize-winning papers from the 2004 NSIS Student Science Awards competition and the report on the NSIS 2003-2004 season.

As the original printings of *The Flora of Nova Scotia* have run out, the Council, in response to a number of requests, has agreed to have it reproduced. This publication prepared by AE Roland and EC Smith was published originally by the NSIS in two parts: Part I The Pteridophytes, Gymnosperms and Monocotyledons in 1966 and Part II The Dicotyledons in 1969 (a total of 703 pages). In the summer of 2005 the two parts were scanned, combined into a single large issue and offered for sale in August 2005. This edition is an exact copy of the original NSIS publication and has received a favourable reception.

Preparation of Volume 43 Part 2 is well in hand. Currently, copy is being prepared for the printing of the galleys. It is anticipated that this issue will be printed and distributed early in the coming summer. The contents will include the long promised written marine science symposium, plus 5 papers from the 2005 NSIS Student Science Awards competition and the report on the NSIS 2004-2005 season.

Respectfully submitted to the AGM
May 1, 2006
James E. Stewart
Editor NSIS

TREASURER'S REPORT

ASSETS:

Bank Account	$6,355.81		
Petty Cash	0.00		
		6,355.8 1	
Investments		52,529.73	
			58,885.54
Account Receivable			**58,885.54**

LIABILITIES AND NET WORTH:

Accounts Payable	
Science Fair cheques	300.00
Student Writing Competition	850.00
Dalhousie University (Proceedings Mailout)	1436.00
Total Liabilities and Net Worth	**56,299.54**

INVESTMENTS:

Cash Balance	10,370.51
CIBC Premium T-Bill (short-term)	13,763.22
CIBC Investment Certificate A @4.40% (due Apr 2008)	8,396.00
Can Western Bank Certificate A@3.30% (due April 2006)	10,000.00
Laurention Bank Certificate A @3.675% (due May 2009)	10,000.00
	52,529.73

Revenue

Membership Dues		
Individuals	$2,560.00	
Institutions	716.00	
AGM (2004)	996.75	
Donations	1,098.70	
Sales/Page charges		
Proceedings	2,113.68	
Other	911.00	
Interest (chequing acct)	3.40	
	$8399.53	Total

Expenditures

Advertisement/promotion	$128.54	
AGM (2004)	1,155.43	
Office supplies/postage	339.24	
Rent (Museum)	150.00	
Proceedings	3,950.37	
Donations/Prizes	3,350.00	
Honoraria	100.00	
	$9173.60	Total

Net: ($774.07)

Treasurer's Report (Continued)

Notes

Finances

The Institute's net worth is virtually unchanged from last year ($56,299.54 compared to $56,701.99 for the 04-05).

One of the investments matured in February and will be reinvested shortly along with a second investment that is maturing at the end of April.

I have learned from Sharon Longard that the cost for mailing out the Proceeding in Fall 2005 was not invoiced. The amount ($1436.00) is listed under accounts payable.

We have applied for a $1000 grant from the Museum (Province Nova Scotia). In addition we have applied for a sales tax rebate for charitable organizations amounting to about $1900.

The annual writing competition saw three prizes given out amounting to $850. We also donated $100 to each of the 10 regional science fairs.

I would like to thank Michael Falk and Robert L. White for the informal audit of the NSIS finances which showed a discrepancy of only a few cents. Thus the report stands unchanged.

Membership

Current membership is 126 members:

~ 117 Regular members
~ 5 Student members
~ 4 Life members

Respectfully submitted to the AGM,
May 1, 2006
Stephen Ewart
Treasurer
NSIS

Instructions to Authors

The *Proceedings of the Nova Scotian Institute of Science* publishes papers in English or French. Manuscripts must be typewritten double-spaced with 4 cm margins. Disk copies in Word or WordPerfect are preferred, but must also be accompanied by three paper copies of the manuscript. An abstract of no more than 200 words, free of formulae, must be included at the beginning of the paper, followed by key words or phrases. This should be followed by an introduction, methods, results or observations, discussion and references. In some cases a combination of these sections may be more effective. Underline only material to be set in italics, and use capital letters only when the letters or words should appear in capitals in the printed paper. Layout and style should follow that used in recent volumes. Each page of the manuscript should be numbered, the first page carrying only the title, authors' names and affiliations and any necessary footnotes. Spelling should follow that of Webster's Third New International Dictionary. Abbreviations, nomenclature, and symbols for units of measurements should follow international recommendations. SI units should be used whenever possible. Use day-month-year sequence for dates. Do not use periods after abbreviations. Photographs should be mounted on Bristol board ready for reproduction. Prints must be of high quality on glossy paper with no space between those mounted in groups. Color illustrations will be accepted at the discretion of the Editor. The cost of color reproduction is borne fully by the authors who must submit a statement accepting this responsibility. References are to be collected at the end of the paper and referred to in the text by inclusion of the author's name and year of publication. The list of references should be consistent with the following examples:

Periodicals	Nielsen KJ, Franz DR (1995) The influence of adult conspecific and shore level on recruitment of the ribbed mussel *Geukensia demissa* (Dillwyn). J Exp Mar Biol Ecol 188:89-98
Books	Cushing D, Walsh J (1976) The ecology of the seas. WB Saunders Company, Toronto
Papers from books or symposium proceedings	Lee GF (1975) Role of hydrous metal oxides in the transport of heavy metals in the environment. In: Krenkel PA (ed) Heavy metals in the aquatic environment. Pergamon, Oxford, p 137-147
Pers. comm.	Smith AJ (2001) (Nova Scotia Department of Agriculture, Halifax) Personal communication

Tables should be numbered consecutively in bold-faced Arabic numerals and must have brief titles that are self-explanatory; each table must be typed on a separate page.

Illustrations are to be numbered consecutively in Arabic numerals. Captions should be self-explanatory and typed on a separate page. Two paper copies of each are required even when they are embedded in an electronic file. All lines in drawings must be of suitable thickness to reproduce well when published in the *Proceedings*. Similarly, letters and symbols in drawings should be at least 2 mm high when reduced to the size used in the *Proceedings*.

Page Charges. Currently a charge of $25 per page is levied to help defray the cost of publication. This amount is charged to the institution or a contract supporting the research reported in the published paper. In no case will acceptance of the paper be dependent upon payment of the page charges.

Authors are responsible for editing the galley proofs. Orders for reprints, in addition to the 15 supplied gratis to the corresponding author, must be received when the galley proof is returned.

Papers should be sent to the Editor:

JE Stewart, Department of Fisheries & Oceans
Bedford Institute of Oceanography, PO Box 1006
Dartmouth, NS, Canada B2Y 4A2
E-mail: stewartje@mar.dfo-mpo.gc.ca

Recommandations aux auteurs

Le *Proceedings of the Nova Scotian Institute of Science* publie des articles en anglais ou en français. Les documents soumis doivent être dactylographiés à double interligne avec des marges de 4 cm. On préfère recevoir le texte sur disquette en format de traitement de mot Word ou WordPerfect ainsi que trois copies imprimées. Au début de l'article, on exige un résumé n'excédant pas 200 mots, sans formules et suivi de mots ou d'expressions clés. Cette partie devrait être suivie par l'introduction, les méthodes, les résultats ou observations, la discussion et les références bibliographiques. En certain cas, il sera peut-être plus efficace de combiner quelques parties. Soulignez seulement ce qui devrait paraître en caractères italiques et écrivez avec une majuscule seulement ce qui devrait être imprimé en majuscule. Les détails de présentation et de style devraient suivre un numéro récent de la publication. Chaque page de l'article devrait être numérotée et la première page ne portera que le titre, les noms d'auteurs, leurs adresses respectives et toute note infrapaginale qui s'imposera. L'orthographe doit suivre Le Grand Robert et les accents doivent être insérés sur les majuscules. Les abréviations, la nomenclature et les symboles seront conforme aux recommandations internationales. Où possible, utilisez le Système international d'unités. N'ajoutez pas de point aux abréviations. Les photographies devraient être montées sur une carte Bristol prêtes à reproduire. Les épreuves doivent être de qualité supérieure et aucune espace devrait séparée une collage d'un groupe de photographies. Les illustrations en couleurs seront acceptées comme l'éditeur scientifique jugera à propos. Les coûts de reproduction en couleurs seront aux frais des auteurs qui devront émettre une déclaration acceptant cette responsabilité. Les références bibliographiques devraient paraître à la fin de l'article et devraient être citées dans le texte à l'aide des noms d'auteurs et de l'année de publication. Veuillez, s'il vous plait, abréger les titres des journaux selon le 'BIOSIS Serial Source', dernière édition, et respecter strictement le format PNSIS (voir les exemples suivants).

Périodiques	Nielsen KJ, Franz DR (1995) The influence of adult conspecific an shore level on recruitment of the ribbed mussel Geukensia demissa (Dillwyn). J Exp Mar Biol Ecol 188: 89-98
Livres	Cushing D, Walsh J (1976) The ecology of the seas. WB Saunders Company, Toronto
Articles de livres ou de compte rendu	Lee GF (1975) Role of hydrous metal oxides in the transport of heavy metals in the environment. In: Krenkel PA (ed) Heavy metals in the aquatic environment. Pergamon, Oxford, p 137-147
Communication personnelle	Smith AJ (2001) (Nova Scotia Department of Agriculture, Halifax) Personal communication

Les tableaux doivent être numérotés de façon continue en chiffres arabes et en caractères gras. Chacun doit comporter un bref titre qui s'explique de soi même et doit être dactylographié sur une page distincte.

Les illustrations sont numérotées en chiffres arabes selon leur ordre séquentiel. Les légendes devraient s'expliquer de soi même et devraient être dactylographiées sur une page distincte. On exige deux copies imprimées de chaque illustration même quand elle fait partie d'un fichier électronique. L'épaisseur des lignes sur une illustration doit être suffisante pour que la reproduction soit nette à la grandeur de la publication. De façon semblable, le lettrage et les symboles des illustrations devraient être au moins 2 mm de haut quand elles paraîtront dans le Proceedings.

Frais de publication. Des frais de 25,00 $ par page sont présentement imposés afin de subvenir une portion des frais de publication. Ce montant est imputé à l'institution ou au contrat qui appuie la recherche présentée dans l'article. L'acceptation de l'article pour publication ne reposera jamais sur le paiement des frais de publication.

Les auteurs sont responsables pour la revue des épreuves en placard. On doit recevoir les commandes pour des tirés à part, en plus des 15 qui sont fournies gratuitement à l'auteur correspondant(e), quand vous retournerez les épreuves à placard.

Soumettez vos articles à l'editeur scientifique:

M. JE Stewart, Ministère des Pêches et des Océans
Institut océanographique de Bedford, CP 1006
Dartmouth (Nouvelle-Écosse) Canada B2Y 4A2
Par courriel : stewartje@mar.dfo-mpo.gc.ca

PROCEEDINGS
of the
Nova Scotian Institute of Science
HALIFAX, NOVA SCOTIA

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Volume 44 2008 Part 2
Completion of Vol 44

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Continued on back cover

Layout by Gail LeBlanc; Printing by Halcraft Printers Inc.
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The Nova Scotian Institute of Science

- The Nova Scotian Institute of Science was formed in 1862 from the Halifax Mechanics Institute (1831-1860) and the Halifax Literary and Scientific Society (1839-1862) making it one of the oldest learned societies in Canada.
- Among the Institute's roles are the stimulation of scientific research and provision of scientific information to scientists and the general public through meetings and publication of the Proceedings of the Nova Scotian Institute of Science. The Institute provides scientists, technologists, educators and administrators with an opportunity to communicate with each other and to the community through public lectures, panel discussions, its Proceedings and the Internet.
- The Institute has a library, established in 1864, now housed in the Killam Library at Dalhousie University; it has a number of periodicals not available elsewhere in Canada.
- Prominent members of the scientific community are invited to address the Institute at a series of regular meetings held on the first Monday of each month from October to May. The lectures and panel discussions are free and open to the public; the topics are of broad interest. The meetings take place usually at the Nova Scotia Museum of Natural History, 1747 Summer Street, Halifax at 7:30 PM. For topics, meeting locations and more information on the Institute please consult the NSIS website:
  http://www.chebucto.ns.ca/Science/NSIS
- Membership in the Institute is open to anyone with an interest in science. Information on joining can be obtained from the NSIS website and Council members.

Proceedings of the Nova Scotian Institute of Science

Sponsored by the Nova Scotian Institute of Science and supported in part by a grant from the Nova Scotia Museum, the Proceedings produces one or more issues per year and will consider for publication original articles principally, but not exclusively, in the areas of natural and engineering sciences as well as papers emanating from studies in the health professions. Papers that develop new scientific theories based on scientific principles and/or analysis of data particular to Nova Scotia or the Atlantic Provinces are especially encouraged.

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Volume 44, Part 2, pp. 109-123

NEW DISTRIBUTION RECORDS FOR FLOWERING PLANTS IN ANTIGONISH COUNTY, NOVA SCOTIA

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Antigonish, Nova Scotia B2G 2W5

Distributions of over 50 species of flowering plants from Antigonish County, Nova Scotia are presented based on collections made primarily over the last ten years. Some of these are new county records representing range extensions from the western and central parts of the province. Many are new records for the eastern mainland and north shores of the province. Rare species discussed are *Asclepias incarnata*, *Comandra umbellata* and *Triosteum aurantiacum*. Several species, including *Asparagus officinalis*, *Centaurea cyanus*, *Lathyrus latifolius*, *Lysimachia nummularia*, and *Origanum vulgare*, likely represent recent or older garden escapes. *Sedum ochroleucum* is reported outside of cultivation for the first time from Nova Scotia, based on a single population that has been established for at least two years.

On décrit la répartition de plus de 50 espèces d'angiospermes dans le comté d'Antigonish (Nouvelle-Écosse), d'après des collectes effectuées essentiellement les dix dernières années. Il s'agit parfois de nouveaux cas signalés dans le comté, représentant des prolongements de l'aire de répartition depuis l'ouest et le centre de la province et, dans bien d'autres cas, de nouveaux signalements pour l'est de la péninsule et les côtes nord de la province. Les espèces rares présentées sont *Asclepias incarnata*, *Comandra umbellata* et *Triosteum aurantiacum*. Plusieurs espèces comme *Asparagus officinalis*, *Centaurea cyanus*, *Lathyrus latifolius*, *Lysimachia nummularia* et *Origanum vulgare* sont vraisemblablement des plantes échappées de cultures. *Sedum ochroleucum* est signalé pour la première fois à l'état sauvage en Nouvelle-Écosse, dans une seule population établie depuis au moins deux ans.

INTRODUCTION

Nova Scotia has a long history of floristic study (e.g., Macoun 1889) that culminated in the floras by Roland and Smith (1966, 1969) and its most recent revision by M. Zinck (Roland 1998). The extensive collections on which this flora is based are housed primarily in the E.C. Smith and Roland Herbaria (ACAD and NSAC; herbarium abbreviations follow Holmgren and Holmgren (1998)) with important additional collections also housed in the Nova Scotia Museum (NSPM). These collections provided the basic floristic and distributional information on which Roland (1998) is based. Despite this wealth of collections, the flora of several parts of the province, including Antigonish County, is incompletely known.

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Over the last ten years there has been a concerted effort to enlarge the Herbarium at St Francis Xavier University (STFX) to provide a reference collection of vascular plants for the eastern and northern mainland of Nova Scotia. Most groups are well represented in STFX, except for the Poaceae to which only a limited collecting effort has been devoted. Two extensive studies on flowering phenology were carried out in the fall of 2001 and fall and early winter of 2005-06 (Taylor & Garbary 2003, 2007). Here we report on plant collections that represent new distributions for Antigonish County or plants considered rare in Nova Scotia for which we have discovered significant populations in the County.

MATERIALS AND METHODS

Unless noted otherwise, all of the collections referred to in this paper are based on voucher specimens deposited in the Herbarium of St Francis Xavier University (STFX), in Antigonish. Most of the collections were made by two of us (DJG and BRT) since 1998, with significant additions by the other authors and our various colleagues, student assistants and research technicians.

We define rare plants as those that are numerically infrequent at some spatial scale. The Atlantic Canada Conservation Data Centre (ACCDC) maintains a list of rare plants in the province, while the Nova Scotia Department of Natural Resources (DNR) has classified most species according to the degree to which their provincial populations are at risk of extirpation, as green (secure), yellow (vulnerable) or red (threatened). Rarity is only one element determining whether a species is at risk. We used these lists, along with distributional information in Roland (1998) and older data in Pronych and Wilson (1993) to determine rarity.

RESULTS

Abutilon theophrasti Medik (Malvaceae)

A single non-flowering plant was collected from a cornfield adjacent to South River in 2001. This is a minor range extension from Pictou Co.

Allium schoenoprasum L. (Liliaceae)

Three records from waste ground in Antigonish Co. are likely garden escapes, but provide first observations of this species in the wild from the eastern mainland or north shore of Nova Scotia.

Anthemis tinctoria L. (Asteraceae)

Several collections were made from the same population on a roadside in Antigonish during the fall of 2005. This species is widely distributed in the western part of the province, with Truro being the nearest location to Antigonish (Roland 1998).

***Aronia arbutifolia* (L.) Ell. (Rosaceae)**

Roland (1998) refers to this species as occurring primarily in the south-western part of the province and extending east to Colchester Co. There is a single collection from Antigonish Co. at Pomquet Beach Provincial Park, where *A. arbutifolia* forms part of the heath vegetation on old dunes.

***Asclepias incarnata* L. (Asclepiadaceae)**

This species has recently been collected from marshy, productive soil in the outflow of Gaspereaux Lake and in similar habitat in the East Branch St Mary's River below Lochaber Lake (Guysborough County). *A. incarnata* is uncommon in the province; ACCDC (2007) reports observations from most southern and central counties, but not Antigonish or Pictou counties. The plant appears to have narrow habitat requirements, specifically for saturated ground very near (or in) flowing water. In both populations, the plants were growing in part to full sun among lush marshland vegetation of grasses and forbs.

***Asparagus officinalis* L. (Liliaceae)**

Five collections of this widely cultivated species have been made in Antigonish County. Three are from roadsides (St Andrews, Lochaber and Antigonish), the fourth on the St FX campus, and the fifth on waste ground at Pomquet Point. These are the first records for this species from the eastern mainland or north shore of Nova Scotia. The closest previous record is from Truro (Roland 1998). *A. officinalis* grows well among roadside grass; the colony in St. Andrews has persisted for at least 8 years.

***Aster borealis* (T. & G.) Prov.**

Roland (1998) refers to this species as uncommon and shows no occurrences in the northern mainland of Nova Scotia. We have a single specimen from typical habitat for *A borealis*: the gravelly shore of Lochaber Lake.

***Aster ciliolatus* Lindl. (Asteraceae)**

This species was originally found as part of the fall flowering survey of 2001 (Taylor & Garbary 2003) and many plants were noted during the 2005 fall phenology study. It is evidently common in Antigonish County. Roland (1998) notes its distribution in adjacent Guysborough Co.

***Bellis perennis* L. (Asteraceae)**

This species was initially reported from Nova Scotia by Macoun (1889) based on plants from the extreme southern end of the province and from North Sydney. The two plants collected on waste ground in Antigonish in 2001 (Taylor & Garbary 2003) are therefore a significant find. Return visits to the same site in 2005 and 2006 did not reveal additional plants.

***Berteroa incana* (L.) DC. (Brassicaceae)**

A single collection of this species was made in November 2005 from Antigonish. The plants occurred as a small population adjacent to a seed

and agricultural supply outlet in Antigonish. This is the only collection of the species east of the Annapolis Valley, where it can be an aggressive weed in fields (Roland 1998).

***Carex lupulina* Willd. (Cyperaceae)**

A single collection from the shore of eutrophic Lake St Joseph provides a range extension east from Pictou Co (Roland 1998) and the only record from Antigonish Co. ACCDC (2007) reports *C. lupulina* only from Colchester and Hants counties.

***Centaurea cyanus* L.**

This species is widely scattered through the province; however a single collection from a roadside in gravel and sand represents the only record from Antigonish Co or from the north shore of Nova Scotia (Roland 1998).

***Comandra umbellata* (L.) Nutt.**

This species is considered rare in Nova Scotia with a known distribution in Cape Breton and Pomquet Beach in Antigonish County. DNR classifies *C. umbellata* as a red (potentially endangered) species. Recent collections verify the Pomquet site and added Beshong Cove in Tracadie Harbour as well as Doctor Island in Caribou Provincial Park, Pictou Co. Both sites support substantial colonies of *C. umbellata*, and suggest a strong preference for coastal habitats. This species may be better considered under-collected rather than rare.

***Draba verna* L. (Brassicaceae)**

This tiny plant is abundant at two sites in Antigonish Town and County, both of which are campgrounds. The plants are conspicuous in April and May when the small white flowers and the dense inflorescences can form a haze 2-5 cm off the ground. Local plants have two leaf dimensions. The most common form has small leaves (5-8 × 2-5 mm), giving a rosette diameter of 13-17 mm. A larger and much less common form has leaves 13-18 × 4-5 mm. Our records from Antigonish provide the only collections of *D. verna* from the northern mainland of Nova Scotia.

Draba verna has been reported from other campgrounds and tourist facilities with gravel parking lots, such as Grand Pré National Historic Park (Newell 2006). This habitat reflects a near-perfect fit between the biology of the plant and human activity. These annual plants thrive on compacted, disturbed ground that is continuously maintained in this state by the nature of the land use (i.e., parking for camper-trailers). The plants flower and set seed during April and May before significant vehicular or pedestrian traffic. The seeds can then be picked up by vehicle tires or footwear and transported within hours to equivalent sites where deposited seeds may also grow well. Oldham and Zinck (1997) report a number of "campground" species of similar growth habits.

***Erucastrum gallicum* (Willd.) O.E. Schulz. (Brassicaceae)**

This species is common in Antigonish Town and County; several collections have been made from waste ground. *E. gallicum* was a conspicuous part of the late fall-flowering flora in both 2001 and 2005 (Taylor & Garbary 2003). Roland (1998) provides only two distribution points in the province: one in Kings Co and the other at Truro.

***Erythronium americanum* Ker-Gawler (Liliaceae)**

A single collection from Eigg Mountain, Antigonish, provides a slight eastward range extension from Pictou Co.

***Euphorbia helioscopa* L. (Euphorbiaceae)**

Roland (1998) reported this species to be "occasional but rarely abundant" and suggested that it's prevalence was declining. In our area, *E. helioscopa* is common to abundant at many sites in the Town of Antigonish (mostly waste ground) and adjacent rural areas of the County. *E. helioscopa* was among the most conspicuous members of the late fall flora in 2001 and 2005 (Taylor & Garbary 2003).

***Hieracium X flagellare* Willd. (Asteraceae)**

This hybrid hawkweed has been found only once in Antigonish Co., at Frasers Mills. Other than a record from northern Cape Breton, this is the first collection east of Truro or from along the north shore of Nova Scotia (Roland 1998). The plant was growing in a large meadow among large populations of the parent species.

***Hieracium kalmii* L. (Asteraceae)**

Roland (1998) does not give distribution details for the mainland records of *H. kalmii* ("scattered in central parts of the province"), but notes it is most common in Cape Breton. Records from ACCDC (2007) for the subspecies *H. k. fasciculatum* and *H. k. kalmii* are all from the central part of the province as well. Four collections of *H. kalmii* from two sites in Frasers Mills provide the only records from Antigonish Co, though we have observed *H. kalmii* in a number of locations, such as along overgrown fencerows. *H. kalmii* appears to be relatively common in Antigonish County.

***Hieracium paniculatum* L. (Asteraceae)**

At least three collections of *H. paniculatum* have been made in Antigonish Co. since 2002. This species seems to be quite common on roadsides in this area. Previously, *H. paniculatum* was known only from the southern and western part of the province, with the most easterly records from Halifax Co (Roland 1998, ACCDC 2007).

***Hudsonia tomentosa* Nutt. (Cistaceae)**

This species has one of the most restricted distributions among flowering plants in Nova Scotia. It was previously known only from a few coastal sand dunes in Pictou Co (Roland 1998). In the early 1990s, *H. tomentosa*

was observed in an equivalent habitat at Pomquet Beach Provincial Park, Antigonish Co, by one of us (RL); a specimen from this population has been deposited in the Nova Scotia Museum (NSPM). The occurrence of *H. tomentosa* adds to the distinctiveness of Pomquet Beach Park, which is already home to a number of plant species with highly restricted provincial distributions, such as *Cyperus filiculmis* and *Comandra umbellata*.

***Impatiens glandulifera* Royle (Balsamiaceae)**

There are two collections of this showy garden escape from Antigonish Co. Both plants were growing on semi-shaded hillsides, in roadside ditches. One collection comes from a substantial population occupying both sides of the road. *I. glandulifera* was previously known from Brier Island eastward to Pictou Co (Roland 1998).

***Juncus conglomeratus* L. (Juncaceae)**

This is the first record of this species from the eastern mainland of Nova Scotia. It was found at Lower South River on wet ground along a river backwater.

***Lamium amplexicaule* L. (Lamiaceae)**

This species was found in Antigonish Co in 2001 as part of the phenological study of Taylor & Garbary (2003). *L. amplexicaule* was previously recorded only as far east as Truro and is considered to have an extremely local distribution (Roland 1998). The site where the plants were found has since been disturbed by soil and gravel dumping and the only known population in Antigonish Co is now extirpated.

***Lathyrus latifolius* L. (Fabaceae)**

L. latifolius is described in Roland (1998) as an occasional escape from cultivation, with records only from Kings and Shelburne Counties. Two independent populations of *L. latifolius* have been found here. Numerous plants were scattered through a flood plain of the Wrights River in Antigonish in 2006. The habitat included an old stream bed with sandy soil, and richer meadows. The plants were usually at the margins of alder or willow thickets, although some grew in the open in dense, herbaceous vegetation.

A more extensive population grows in Clydesdale, near Antigonish. For about a kilometre, *L. latifolius* is abundant in herbaceous vegetation along the roadside. The extensive populations of *L. latifolius* in Antigonish Co suggest that it has become fully naturalized; its abundance at Clydesdale suggests it has the potential to become invasive.

***Lotus corniculatus* L. (Fabaceae)**

Roland (1998) refers to this species as occurring from Yarmouth to Colchester Co. However, *L. corniculata* is common and widely distributed in Antigonish Co. It may form a conspicuous part of the wildflower community in dry old fields and roadsides.

***Luzula luzuloides* (Lam.) Dandy and Wilmott (Juncaceae)**

The single collection of this species is the first from the northern or eastern mainland of Nova Scotia (Roland 1998), although its habitat and local abundance elsewhere suggest it is probably more common. Our collection is a small, solitary plant that occurred in an open, mixed forest on wet ground.

***Lysimachia nummularia* L. (Primulaceae)**

Roland (1998) states that this species is occasional from Yarmouth to Truro and "probable" elsewhere in the province. Three collections from four sites have been made in the Town of Antigonish. The first is on the campus of St Francis Xavier University where it may represent a recent garden escape. A second small population occurred at the margins of the Town of Antigonish municipal yard. This population may have originated from one of the soil dumps that are common on the property.

The two other populations are extensive. One occurs in a meadow (as of July 2006) at the town margin where the herbaceous vegetation grows up to 1 m high. Numerous individuals of *L. nummularia* form extensive ground cover here, in several discrete patches. The final population was discovered on disturbed ground (a former gas station) where numerous plants were present among the herbaceous vegetation.

***Malva rotundifolia* L. (Malvaceae)**

Several collections have been made from a cornfield at Frasers Mills, in the interval of South River. The nearest known location based on Roland (1998) is Truro. Although considered uncommon, *M. rotundifolia* probably occurs elsewhere in Antigonish Co as an agricultural weed.

***Medicago sativa* L. (Fabaceae)**

Previously known from the western and central parts of the Province east to Colchester Co (Roland 1998), alfalfa has become widely distributed and common in Antigonish Co. It occurs in a variety of habitats from roadsides to old fields and even the sand dunes at Mahoney's Beach. Alfalfa is widely planted as a forage crop; the wild populations are probably adventive from hayfields.

***Mentha aquatica* L (Lamiaceae)**

A single collection of *M. aquatica* was made from Beauly, Antigonish Co, by one of us (RL) and identified by M Munro of the Nova Scotia Museums. According to Roland (1998), previous collections date from the early twentieth century, when plants were reported from Pictou and Truro.

***Myosotis arvensis* (L.) Hill (Boraginaceae)**

Several collections from Antigonish Town provide the only records for the mainland of Nova Scotia east of Truro. The plant was abundant at all sites where it was found.

***Origanum vulgare* L. (Lamiaceae)**

A few plants were found in early November on waste ground beside a newly built residence at Archibald's Point on Antigonish Harbour. The plants were no longer in flower, but had well developed fruits. Roland (1998) includes New Glasgow (Pictou Co) as part of the distribution of *O. vulgare*. Archibald's Point is very close to the original European settlement on Antigonish Harbour at Town Point, so there have been many opportunities for this species to become naturalized.

***Panicum capillare* L. (Poaceae)**

A single specimen of witch grass was collected in 2000 from a farm lane running through dense forest in an interval of South River. This is the first collection of this introduced grass in northern mainland Nova Scotia.

***Physalis heterophyla* Nees (Solanaceae)**

A single specimen of *P. heterophylla* was found in November 2005 along Brierly Brook in the Town of Antigonish. This is the first apparent record of this species east of Truro. (Roland 1998).

***Physocarpus opulifolius* (L.) Maxim (Rosaceae)**

This small shrub, commonly known as ninebark, is an escape from cultivation. Roland (1998) mentions cryptically that it has been collected "at several localities throughout the mainland." Ninebark has been collected twice here, from roadside thickets near Dunmore and beside Loch Katrine, both in the South River basin. However, *P. opulifolius* has been observed growing abundantly along roads and fence rows over a 15 km distance between and beyond the two collection sites, suggesting it may have established a naturalized population in this valley.

***Portulaca oleracea* L. (Portulaceae)**

Roland (1998) reports that *P. oleracea* (common purslane) is a well-established agricultural weed in the Annapolis Valley, and is spreading rapidly to the rest of the province. Nevertheless, the nearest record to Antigonish County is at Truro. *P. oleracea* was collected in 2006 at an unshaded, gravel boat launch on the shore of St. Joseph Lake, along with other garden weeds. Presumably the seeds arrived on vehicle wheels. In 2007, *P. oleracea* was collected from a vegetable garden in Frasers Mills. Earlier, the plant was observed growing in a flowerbox in Antigonish and in a garden on the St FX campus. *P. oleracea* is a pioneer colonizer of bare ground and is therefore ideally suited to these habitats.

***Potamogeton obtusifolius* Mert. & Koch (Potamogetonaceae)**

This species of slender-leaved pondweed is rare in Nova Scotia, but is known from Antigonish County (ACCDC 2007). *P. obtusifolius* has been collected recently from eutrophic Lake St Joseph, where it forms a minor component of a diverse and productive community of at least five *Potamogeton* species and as many other species of submersed vascular plants.

A second collection has been made from a backwater of South River near St Andrews. Both sites are shallow, warm-water systems with high concentrations of nutrients and dissolved ions, and modest water movement. Roland (1998) mentions that *P. obtusifolius* may hybridize with closely related *P. pusillus*. Specimens of this hybrid have been collected twice from Antigonish Co, from Lochaber Lake and South River. The presence of both parent species (*P. pusillus* is common here) evidently promotes hybridization.

***Potentilla canadensis* L. (Rosaceae)**

Although this species is reported from both the mainland of Nova Scotia and Cape Breton, Roland (1998) does not list any sites from counties along the north shore of Nova Scotia. The single collection from 2001 (Taylor & Garbary 2003) was from waste ground in the Town of Antigonish. This site has now been disturbed for housing construction. There have been no subsequent collections.

***Rhamnus frangula* L. (Rhamnaceae)**

European alder-buckthorn was previously found in pastures and roadsides near towns in the south and central parts of the province. The nearest record in Roland (1998) is from Truro, and there is a single collection in ACAD from East Branch River St. John, Pictou County (under the old name *Frangula alnus*). *R. frangula* has been collected several times from similar habitat in Antigonish County. The species is well established as trees of considerable size (up to 5 m) in a low-lying area of second-growth forest on the St. FX campus. The forest appears to be overgrowing an old homestead. Another specimen was taken from wet forest along the edge of disturbed marshland elsewhere in the Town of Antigonish, a third in young deciduous forest near Upper South River.

***Rorippa nasturtium-aquaticum* (L.) Hayek and *R. sylvestris* (L.) Besser (Brassicaceae)**

These two species of cress may be abundant in slow-moving rivers (*R. nasturtium-aquaticum*) or open land (*R. sylvestris*), but previously the nearest collections were from Truro and Pictou County (Roland 1998). *R. nasturtium-aquaticum* has been collected from two sites in Antigonish County, at Ashdale (farm swale) and Frasers Mills (South River). *R. sylvestris* has been collected once along the bank of Brierly Brook in the Town of Antigonish.

***Schoenoplectus pungens* Vahl. (Cyperaceae)**

The status of this species (common threesquare) in the province is unsettled. Roland (1998) notes only a single collection of *S. pungens* (as *Scirpus pungens*) in Nova Scotia, from Shelburne County, but the Flora of North America (http://hua.huh.harvard.edu/FNA) includes Nova Scotia in the range for the species. Closely related *S. americanus* is known from Yarmouth and Digby Counties (ACCDC 2007). A single collection of *S. pungens* was made from a ditch draining a soccer pitch on the St. FX campus

in 2004. As the soccer field had been constructed only a few years earlier, one wonders if *S. pungens* seed was imported with topsoil or grass seed for the field. The ditch has since infilled naturally and other species have replaced the clump of *S. pungens*.

***Sedum ochroleucum* Chaix (Crassulaceae)**

This is the first report of this species in Nova Scotia. It occurred as a number of plants extending over at least several square metres at the margin of the municipal yard for the Town of Antigonish. The plants were growing in full sun on a poor, gravelly soil along with other herbaceous plants. Given the highly intertwining rhizome and dense cover, the number of individual plants at the site cannot be determined. However, the population had about 100 conspicuous inflorescences that reached about 15 cm in height. This population was first noted in the fall of 2005, but no plants were collected then. A formal collection was made in 2006 and the population persisted through the summer of 2007.

Among *Sedum* spp. reported previously for Nova Scotia, *S. ochroleucum* (European stonecrop) is closest to *S. acre* L.; however, the flowering shoots and larger leaves of *S. ochroleucum* are diagnostic. The latter species has rhizomes without leaves, and vegetative shoots with slightly flattened, apiculate leaves, 7-9 mm long. About 12, tightly clustered, bright-yellow flowers, 1 cm in diameter, form at the apex of special shoots on which the leaves are fewer and less pigmented. The local population has flowers with up to eight sepals and petals.

S. ochroleucum has been previously noted from Maine, Massachusetts and Vermont in New England. There are no records from eastern Canada. *S. ochroleucum* can tolerate to hardiness Zone 5 and thus may persist if the site is not destroyed by human activity. This fate is quite likely because soil and gravel are routinely dumped at the municipal yard.

The United States Department of Agriculture includes *S. ochroleucum* in their list of invasive and noxious weeds (http://plants.usda.gov). *S. ochroleucum* seems unlikely to become invasive in Nova Scotia, however because appropriate habitat is rare. Moreover, the species propagates vegetatively rather than by seeds, which would further inhibit it spreading to new sites.

***Sinapis alba* L. (Brassicaceae)**

According to Roland (1998), white mustard has been recorded only from Kings Co. It has been found in the late-flowering studies of both 2001 and 2005 (Taylor & Garbary 2003) in and around the Town of Antigonish. *S. alba* tends to occur on highly disturbed ground where there is little competition.

***Solidago caesia* L. (Asteraceae)**

Roland (1998) points out that there are no recent collections of *S. caesia* and suggests that earlier records may be in error. Nevertheless, it has been reported "throughout north-central regions" which probably does not

include Antigonish Co. There is a single collection in STFX from Frasers Mills, where it was growing along an old logging road, and we have observed the species occasionally in similar habitat.

***Thymus serpyllum* L. (Lamiaceae)**

A single collection was made in 2001 from a neglected flower box on Main Street in Antigonish (Taylor & Garbary 2003). Other collections range south and west from Pictou Co (Roland 1998), so wild thyme is not unexpected here.

***Trifolium arvense* L. (Fabaceae)**

Rabbitfoot clover was previously reported from Kings to Pictou Counties; Roland (1998), points out that it is often confluent along roadsides. *T. arvense* grows on the gravel shoulders of all the major highways in Antigonish County; collections have been made from Highway 104 (TransCanada Highway) at Lower South River and at Havre Bouchie, and from Highway 316 at Frasers Mills (and again in Guysborough Co., where it grows in pure stands for considerable distances). A further collection was made from the shoulder of a gravel road (West Ohio) and another from mixed herbaceous vegetation growing on an abandoned bridge. *T. arvense* has recently been observed on an overgrown gravel driveway and along a walkway on the St. FX campus. This species appears to be spreading quickly.

In a manner similar to that for *Draba verna* in campgrounds, road construction has apparently selected for, and facilitated, a species which is ideally suited to that habitat. Specimens of *T. arvense* from road shoulders may be dwarfed (Roland 1998) and have comparatively long tap roots, presumably as an adaptation to the dry gravel. Nevertheless, the plant is able to establish large populations in the absence of shade or competition. Although roadsides are only 1-2 m wide, they are continuous and intersecting over the entire Province, providing *T. arvense* unrestricted access to all the habitat without barriers between patches. Automobile tires provide a ready means of seed transport to uncolonized areas, while periodic highway maintenance prevents competing species from colonizing.

***Triosteum aurantiacum* Bickn. (Caprifoliaceae)**

This species is considered rare in Nova Scotia (ACCDC 2007), and is classified as yellow (vulnerable) in the DNR ranking. Although it has been previously reported from Antigonish Co (Roland et al. 1994), we include it here because *T. aurantiacum* appears to be widespread in suitable habitat within the county. Collections have been made from flood-plain forest along the South River at St Andrews and at Frasers Mills, and near the mouth of Pomquet River, the adjacent drainage. More recent observations reveal a scattered, but more or less continuous, metapopulation along the lower reaches of South River, over a distance of about 10 km. Similar, though smaller, populations extend along the lower reaches of the Pomquet and West rivers.

The species occurs in clumps within early successional forest growing on rich alluvial soil. *T. aurantiacum* appears to make its best growth in clearings. Interestingly, a thorough search of the flood plain of upper South River, above the Frasers Mills Fish Hatchery, did not reveal any specimens of *T. aurantiacum*, apparently because the species is unsuited to mature forest there. Conversely, we have recently observed a disjunct clump of *T. aurantiacum* growing in an overgrown fencerow beside an orchard, ~0.5 km from South River. Clearing of woody undergrowth along the fence, combined with lime applications around the orchard trees (which also attract frugivorous birds), may have facilitated colonization of this species outside its usual habitat. A detailed study of the population distribution of *T. aurantiacum* in Antigonish County is in preparation.

***Utricularia purpurea* Walt. (Lentibulariaceae)**

A single collection of this species in Antigonish Co was made from Taylor Lake, northwest of Lochaber Lake, in 1982. Taylor Lake lies in the West River drainage basin. Roland (1998) included eastern Guysborough Co as part of the distribution for *U. purpurea*, so its occurrence in the western part of Antigonish Co was to be expected.

***Verbena hastata* L. (Verbenaceae)**

Blue vervain is widespread but uncommon in Nova Scotia, becoming most frequent in the counties surrounding the northern Bay of Fundy (Roland 1998, ACCDC 2007). Until 2000, the nearest collection was from Pictou County. *V. hastata* has been collected from three sites on South River (at Frasers Mills, St Andrews, and Lower South River), and from Brierly Brook in downtown Antigonish. The species has been observed in the flood plain of Pomquet River and probably occurs in similar habitat elsewhere.

V. hastata appears to have strict habitat requirements. It is almost always found within a few metres of the river channel, growing either on gravel bars and eyots within the channel, where competition is limited, or less abundantly along the bank among other streamside vegetation. As with *Triosteum aurantiacum*, there appears to be a metapopulation of *V. hastata* scattered in suitable habitat all along the lower reaches of South River, from Frasers Mills to the Antigonish Estuary. Because its preferred habitat is ephemeral, the species does not persist in the same location for many years. Further collecting effort to establish the presence and extent of *V. hastata* populations in other local rivers would be worthwhile.

***Veronica arvensis* L. and *V. longifolia* L. (Scrophulariaceae)**

Roland (1998) cites both these species as occurring from Yarmouth to Pictou Counties. Several collections of *V. arvensis* have been made in Antigonish Co, from lawns and old pasture around Frasers Mills. *V. longifolia* (Garden Speedwell) is an escape from cultivation that persists along roadsides and in thickets (Roland 1998). In Antigonish County, *V. longifolia* was part of the late-blooming flora in 2005. Other specimens have been found along Brierly Brook, within the Town, in July 2006.

***Vicia sepium* L. (Fabaceae)**

Two collections of this old-field species have been made in Antigonish, one as a roadside weed, the other in herbaceous vegetation at the margin of a field. *V. sepium* has a western and central distribution in the province, and is collected only occasionally. The nearest previous record, of only four reported in Roland (1998), was from Pictou Co.

DISCUSSION

The list of flowering plants with new records from Antigonish County totals 54 species. Based on the ranges given in Roland (1998) and the STFX collection, it is estimated that about 700 of the approximately 1500 species of vascular plants known from Nova Scotia (Roland 1998) occur in Antigonish County. These additions therefore constitute an increase of about 7% in the floral diversity of the county, a surprising percentage given the small size of the area and the long history of floral studies in Nova Scotia.

As part of a continuing phenological study, two of us (DJG and BRT) have made systematic observations on the distribution of flowering plants in and around Antigonish Town in the late fall and early winter of 2001 and 2005-2006. This effort revealed 15 of the 54 new species records for Antigonish County. The remaining records arose largely from summertime surveys of particular habitats (e.g., Eigg Mountain – James River Protected Area) or casual collecting in the course of other field work.

A regional flora can never be exhaustive; there will always be new occurrences no matter how thorough the previous collection effort. In addition, the local and regional distributions of species are not static. How much of the augmentation of the flora of Antigonish County can be attributed to under-collecting and how much to range expansions? The answer probably depends upon the ecology of each species.

Weedy species, those adapted to rapid growth on disturbed ground where competition is low, are more likely to be expanding their range in the province than long-lived species of forest and glade. Agricultural weeds in particular are typically introduced as seed contaminants in grain. These species are most likely to establish in the Annapolis Valley or the central part of the province where extensive agriculture creates habitat. Species such as *Abutilon theophrasti* and *Portulaca oleracea* are probably recent migrants to northern Nova Scotia; the discovery of *P. oleracea* on a gravel boat launch strongly supports vehicle traffic as a vector. A similar argument may be applied to *Berteroa incana* (found beside a farm supply store), *Lotus corniculatus*, *Malva rotundifolia*, *Rorippa sylvestris* and *Sinapis alba*. Still, the list of probably recent arrivals to the area is comparatively brief.

An important sub-class within the group of recent migrants are those species capable of thriving on compacted, gravelly soil with frequent physical disturbance but little competition. *Draba verna*, a campground species, and *Trifolium arvense*, spreading rapidly along highway shoulders, are the most prominent local members of this group. Both species presumably

take advantage of vehicle traffic for dispersal; this agent is particularly felicitous for *D. verna*, which would otherwise have difficulty reaching widely separated patches of habitat. Roadsides present similar physical habitat as campgrounds, except perhaps for the presence of de-icing salt. It is worth investigating whether *T. arvense* has unusual salt tolerance.

Most of the remaining species reported here have probably been overlooked. This is almost certainly true of meadow and woodland plants such as the two *Aster* species, *Hieracium* spp., *Solidago caesia* and *Utricularia purpurea*. Rare species, by definition, are easily overlooked. The populations of *Verbena hastata* and *Triosteum aurantiacum* are conspicuous over a wide area within their restricted habitats of river intervals. We have no way of knowing, however, if those populations have historically been so extensive or if they have recently expanded. The lower South River is rebuilding its naturally meandering channel after historical channelization. This process has created a succession of large sand bars and gravelly islands which are habitat for *V. hastata*.

Escapes from cultivation represent a third class of species within our list of new records. Most of these are escapes from ornamental gardens, while others (*Allium schoenoprasum*, *Asparagus officinalis*, *Medicago sativa*) are agricultural escapes. Some of these species may have only recently established here (e.g., *Lathyrus latifolius*, *Sedum ochroleucum*) and therefore were not noted earlier. Others, especially woody species such as *Rhamnus frangula*, must have been established for some years, and would appear to have been overlooked. The recent addition of *Euonymus europaeus* L. (spindle tree) to the flora of Nova Scotia (Garbary & Deveau 2007) suggests that other flowering plants will be revealed growing in Antigonish County.

Our collecting efforts, especially the late-flowering studies (Taylor & Garbary 2003, 2007) have been highly biased toward disturbed ground; conventional botanical collections are probably biased toward natural habitats. This unequal effort may largely explain why so many of the new species on our list are weeds or other early successional species. These species are also more likely to be spreading rapidly. In urban areas, native and established pioneer species on broken ground may be augmented by seeds introduced in turf, fill or grass seed. Gardening and landscaping in urban areas appear to be powerful mechanisms of plant dispersal and therefore of botanical homogenization at a provincial scale.

Aside from disturbed ground, the richest sources of new species were river intervals and lakeshores. While unequal sampling effort is again a factor, it is apparent that alluvial soils in river flood plains represent special habitats of high plant diversity compared with the mixed forests and clearcuts that occupy the uplands. The lower South River alone supports at least six species of provincially rare species, several of them with substantial populations. These habitats are therefore deserving of both more concerted sampling and vigorous conservation.

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REFERENCES

ACCDC (Atlantic Canada Conservation Data Centre) (2007) County-level species occurrence data for Nova Scotia. http://www.accdc.com/products/NCounties.htm [accessed 14 August 2007]

Garbary DJ, Deveau A (2007) The Spindle Tree, *Euonymus europaeus* L. (Celestraceae): A newly naturalized shrub in Antigonish County, Nova Scotia. Can Field-Nat 121:85-88

Garbary DJ, Taylor BR (2007) Flowering during January in Antigonish County, Nova Scotia. Can Field-Nat 121:76-80

Holmgren PK, Holmgren NH (1998 [continuously updated]) Index herbariorum: A global directory of public herbaria and associated staff. New York Botanical Garden's Virtual Herbarium. http://sweetgum.nybg.org/ih/

Oldham MJ, Zinck, M (1997) New and noteworthy records from the vascular flora of Nova Scotia. Can Field-Nat 111: 393-398

Newell, R (2006) (Curator of the Herbarium, Dept Biology, Acadia University, Wolfville, NS) Personal communication

Pronych G, Wilson A (1993) An atlas of rare plants in Nova Scotia. Curatorial Report No 78. Nova Scotia Museum of Natural History, Halifax, Nova Scotia

Roland AE (1998) Roland's Flora of Nova Scotia, 3rd ed Nimbus Publishing Ltd and Nova Scotia Museum, Halifax, Nova Scotia

Roland AE, Smith EC (1966) The flora of Nova Scotia, Part I. The Pteridophytes, Gymnosperms and Monocotyledons. Proc NS Inst Sci 26(2):1-238

Roland AE, Smith EC (1969) The flora of Nova Scotia, Part II. The Dicotyledons. Proc NS Inst Sci 26(4):277-743

Roland M, Covert K, Melanson R, Mills P, Milton R, Power T, Underhill C (1994) Wetland plants of Nova Scotia: Species of concern. Nova Scotia Department of Natural Resources, Kentville, Nova Scotia

Taylor BR, Garbary DJ (2003) Late-flowering plants from northern Nova Scotia. Rhodora 105:118-135

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ARE INDUSTRIALIZED FISHERIES SUSTAINABLE?

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Fish stock assessment and management is currently based on the concept of sustainable surplus production. This essay argues that this concept is fallacious and that the assessment/management models which assume its existence are overly simplistic. The analysis explores some of the other issues which should be considered in any stock management regime: these include the dynamic responses of marine ecosystems to physical forcing, the real significance of the extraordinary fecundity of teleosts, the indeterminate growth pattern of fish and its consequences for the reproductive efficiency of older individuals, so that truncation of the older year classes, an apparently inevitable consequence of fishing, will hasten stock collapses. The long-term future of modern fisheries is not bright.

L'évaluation et la gestion des stocks de poisson sont actuellement fondées sur la notion de production excédentaire durable. Selon la thèse présentée ici, cette notion est fallacieuse et les modèles d'évaluation et de gestion qui la tiennent pour fondement sont trop simplistes. L'analyse envisage certains des autres facteurs qui devraient être pris en considération dans tout régime de gestion des stocks, notamment les réactions dynamiques des écosystèmes marins au forçage physique, la signification réelle de l'extraordinaire fécondité des téléostéens, le régime de croissance indéterminé des poissons et ses répercussions sur l'efficacité de la reproduction des plus vieux individus, qui font que la réduction des plus vieilles classes d'âge, conséquence apparemment inévitable de la pêche, précipitera l'effondrement des stocks. L'avenir à long terme des pêches modernes n'est pas brillant.

INTRODUCTION

It is not easy to apportion blame for the failure of fish stocks, but some of it may certainly be attributed to management advice, even if this was generated by state-of-the-art fishery science agencies: we are all too familiar with a notorious case right here on our doorstep in Atlantic Canada. There are those, myself among them, who believe that this is an inevitable result of the use of simplistic simulation models of the dynamics of populations that are quite unreal: these treat the fished stock as if it inhabited an ideal space containing neither competitors nor elusive food supplies, and they ignore the influence of environmental forcing. The result of the failures of these models, of the difficulty that politicians have in following scientific advice, and in the obduracy of fishermen in cheating on regulations, is before us all.

But the myth that commercial fishing is sustainable, in the world as it is, still lives. Every text on fishery management is based on some version of this selective conjecture, and most of them assume that it was so obviously true

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that alternatives are not discussed. Nevertheless, we are starting to come to terms with the consequences of the simple models developed 50 years ago or more, and individual and agencies are calling for more recognition of the environment in which the stocks live, when planning for their management. Yet I think that the complexity of the marine environment, and the depth of our ignorance of that environment, is not fully comprehended in the stock management strategies now being sketched out for future use.

This short essay is not intended to be a contribution towards relieving that ignorance, but is rather intended to emphasize its depth. Not long ago, Daniel Pauly (2005) suggested that an *"ability to produce a surplus that we can share, year for year, is an emergent property of marine ecosystems, contingent on their continued existence as complex entities"* but it is absolutely not clear to me what mechanisms might produce such desirable emergent properties. I suggest that they might be quite difficult to define and propose a very brief review of some candidate properties that might possibly be considered in the balance: some, I shall suggest, support the possibility that density-dependent growth of fish stocks might give what we have come to call (quite erroneously!) surplus production, while some other properties of teleosts, and of the natural history of the sea, do not at all support the concept.

MARINE AND TERRESTRIAL ECOSYSTEMS

Although we have come a long way since the ecosystem concept was first coined, marine scientists remain shackled in their thinking because the ecological literature is so dominated by studies of terrestrial habitats. Most of what we know (or think we know) about ecosystem function is based on observation of terrestrial or littoral habitats. Unfortunately, this knowledge has limited relevance in the oceans, principally because the dynamics of marine ecosystems respond to changes in external forcing at much shorter time scales than occurs in terrestrial habitats. Consequently, it is very difficult to understand the response of marine biota to their physical environment because we can make observations at appropriate time-scales only with great expense: marine habitats are poorly understood because few have levels of observation remotely comparable to those of, for example, the California Cooperative Oceanic Fisheries Investigations program (CALCOFI 2007), the approximately 40-year Multispecies Trawl Surveys of the major shelf areas of Atlantic Canada (Chadwick et al. 2007) now part of the Atlantic Zone Monitoring Program (AZMP) (Pepin et at. 2005) or the multispecies trawl surveys in the Gulf of Maine (conducted since 1965). Although the dynamic response of marine ecosystems to physical forcing must follow rules that we can aspire to understand, these responses are chaotic in the sense that we are quite unable to predict any future state. It is only after an event, and to the extent that we have observed and described it correctly, that our general knowledge of the biology of individual species may

be sufficient to allow us to suggest what has probably taken place — but we can rarely be sure.

In marine environments, plant growth (and herbivore biomass) responds almost instantaneously to ephemeral changes in upper ocean dynamics, as can be observed in any mesoscale image of surface chlorophyll that is matched with surface elevation to indicate motion. Remember, although these patterns are largely forced by surface wind stress this apparently simple process conceals great complexity, and the surface water mass responds quite differently in cold and warm seas; the change of the Coriolis acceleration with latitude requires that wind stress should preferentially induce mixing in cold seas, but motion in low latitudes. There are many similar complications in the forcing of marine ecosystems that are very different from what we are familiar with in terrestrial ecosystems.

At the regional scale, constant changes in water motion, stratification, convergence and divergence are induced by shifts in the strength and location of the planetary wind systems, especially in the succession of Rossby waves at high latitudes. These shifts are now codified by a series of indices of inter-regional differences in atmospheric pressure — the North Atlantic Oscillation (NAO), Pacific Decadal Oscillation (PDO), Southern Ocean Index (SOT), etc. at a quasi-decadal scale — including the novel Atmospheric Circulation Index (ACI) of Klyashtorin that has a 65-70 year period — and are reflected in the abundance of clupeids in upwelling regions. Consequently, fundamental changes of ecological state are observed to occur naturally in the sea at rates greatly exceeding those observed in terrestrial ecosystems. The ecological consequences of episodes of anomalously low atmospheric pressures and warm sea surface temperatures in the Gulf of Alaska, induced by a shift in one of the principal quasi-permanent meanders in the westerly winds indicated by the PDO are well known.

Changes of state that would seem to be equivalent to a switch from, say, tundra to boreal forest are induced in a few months in the ocean, while such a change could be completed ashore only over several centuries. Further, these are not simple shifts between two steady states, for the pelagic ecosystem is incapable of steady state, being in a perpetually dynamic imbalance; in consequence, the relative and absolute abundance of fish species is everywhere perpetually changing and thus challenging what has been called the *'classical view of sustainability'* — in which an equilibrium biomass of a stock is established as a function of fishing mortality and of the carrying capacity of the habitat.

That fish stocks vary in abundance and location is no new discovery, for already in 1865, Francis Day — then Inspector-General of Fisheries for India — noted that the oil sardines of the Malabar coast were very uncertain in their availability; accordingly, he recommended against a planned expansion of the fishery to supply the new oil and fertilizer factories then being planned. But Day was obviously a better ichthyologist than economist, for the new industry flourished and flourishes still, despite its highly variable resource base. Although on the west coast of India the response of the oil

sardine population to upwelling dynamics is unique (the upwelled water is oxygen-deficient), this is nevertheless one of the now familiar family of responses of clupeid populations of upwelling regions to changes in atmospheric forcing. Oil sardine abundance, as catch data for the 20th century suggest, follows patterns comparable to those of the other, much better known species of clupeids of upwelling regions.

Although clupeid stocks have taken much of our attention, we have also come to understand that all individual fish stocks vary naturally both in abundance and location, more or less strongly depending on many factors, and even in relatively stable parts of the ocean such as the northeast Atlantic shelves. It was there that one of the earliest examples of what we now call regime shifts was observed; the classical "Russell cycle" in the western English Channel with the progressive replacement of herring by pilchard in the early 1930s, in association with reduced primary productivity and copepod abundance, and the return after 1965 to the earlier condition.

Because today we are bombarded with comment (based on another selective conjecture?) that any observed ecological change is related to the effects of the increase in atmospheric $C0_2$, perhaps we should remember what Campden, the 16th century English historian, wrote: "*These herrings, which in the times of our grandfathers swarmed only about Norway, now in our times... swim in great shoals around our coasts every year*". Indeed, from 1550 to 1900 there were four periods when herring were distributed preferentially towards the north, along the Bohuslan coast of Sweden, and five of more southerly distribution (Cushing 1981). There is, of course, an extensive literature to explore that discusses the natural variability of fish stocks, and the complex interactions of this with the effects of fishing mortality.

I have raised these well-known observations here only to suggest — what I cannot demonstrate — that if the marine ecosystem is characterized by more rapid and profound dynamic changes in state than terrestrial ecosystems, then perhaps individual species of fish may have evolved life history characteristics that enable them to respond more effectively than terrestrial vertebrates to rapid changes in the intensity of natural mortality. Certainly, one of the characteristics that distinguishes marine from terrestrial ecosystems is the very high link density of marine food webs compared with terrestrial: connectance - the number of links per species[2] - is very high in the oceans (Dunne et al. 2004). Individuals belonging to marine species encounter a more taxonomically-diverse range of individuals than do terrestrial species: this may offer some support to an argument that this characteristic would enhance the potential ability of populations of marine fish to absorb novel mortality more readily than do terrestrial vertebrates.

Could this be one factor that induces Pauly's emergent property? Is the relative openness of marine ecosystems associated with a greater interregional exchange of species than on land? If this is the case, can marine ecosystems consequently better accommodate the arrival of a novel predator than terrestrial ecosystems?

Observations do seem to point in that direction, because terrestrial vertebrates are extraordinarily sensitive to the arrival of human predation; their populations melt rapidly away when we seriously start to exploit them for food or hides. Bison fecundity was simply no match for the mortality imposed by a novel human predator, and nor could bison sustain their essential migrations after the rapid enclosure of the prairies for ranching.

Subjectively, at least, the history of fishing does suggest that ocean fish stocks are at least a little more resilient, because our efforts to eliminate them have been at least as determined as our ancestor's hunting of mammals on grasslands. Because of the extreme sensitivity of terrestrial mammals to hunting, expanding human populations could obtain sufficient food from the land only by agriculture or animal husbandry and neither of these activities may be sustainable, since the axe and the plough very easily change regional hydrologic cycles and so create aridity and desertification. Then, we should note that while the great majority of the terrestrial vertebrates that have ever been hunted seriously for food were large herbivores, the species targeted by fishing have always been — with just a few notable exceptions — predators.

So fishing has only a minimal impact on the natural productivity of the 'seascape'; oceanic primary production responds principally to variable physical forcing, and only secondarily to changes in abundance of top predators and the consequent release of herbivore populations. Most importantly, fishing does not normally modify the abundance of oceanic herbivores directly, since these are dominated by millimeter-scale zooplankton much too small to interest us as potential food. For this reason, we have comfortably supposed that trophic cascades of the kind observed in lakes or the littoral zone after the removal of top predators do not often occur in the open sea, so that the base of the trophic pyramid that supports the fish in which we are interested is relatively unmodified by fishing (Cury et al. 2001). Unfortunately, we have now learned from an understanding of the consequences of gross overfishing that occurred during the last 30 years or so in the NW Atlantic, that trophic cascades may also occur at sea (e.g. Frank et al. 2005).

Finally getting to the fish themselves, if we are seeking characteristics that might suggest that they are more able to sustain fishing pressure than terrestrial mammals can sustain hunting pressure, I suggest that it might be useful to concentrate on three aspects of teleost biology that strongly differentiate them from terrestrial mammals: *(i) – their extraordinary fecundity, (ii) - their pattern of life-long growth and (iii) - the variability of their annual spawning success*. Unfortunately, only the first of these characteristics might have any potential for decreasing their sensitivity to fishing, while the third would seem to militate against their value for a modern industry which will value supply reliability in its source of raw material.

TELEOST FECUNDITY

Inevitably, when confronted with the question of the potential sustainability of sea fisheries, one starts by thinking about the quite extraordinary reproductive characteristics of teleosts, as people have done since the days of Lamarck, almost 200 years ago.

Teleosts reproduce by means of very many, very small eggs, and their relative fecundity increases progressively with age and weight, at rates greater than linearity. As hardly needs repeating, all other vertebrates have a characteristic fecundity that is 4-5 orders of magnitude smaller. Those who have discussed this phenomenon in the past have tended to assume that such high fecundity evolved in response to the unpredictability of the marine environment so that, after a population crash induced by changes in environmental conditions, the remnant adult stock could rapidly recover its habitual abundance. But Froese and Luna (2004) recently examined the reproductive biology of almost 50 representative teleost species and found "*no significant relationship between annual fecundity (ranging from 368 to 10 million eggs) and maximum annual reproductive rate (ranging from 0.4 to 13.5 replacement spawners per spawner at low population densities)* ".

If this is the case, we have to ask why should many teleosts, alone among vertebrates, have evolved to spend part of their life history as members of the zooplankton? It is certainly odd that general ichthyologists should have concerned themselves so little with explaining why 'typical' teleosts of the open ocean and continental shelves have evolved to produce so many small planktonic larvae rather than brooding, or giving birth to, just a few, large young. This is especially odd given that all elasmobranchs and even some teleosts, the live-bearers and nest-builders, succeed very well with a strategy which requires them to invest material and parental care in the generation of just a few, large young.

Let me examine an alternative proposition concerning the evolution of teleost reproductive habits, while admitting that the argument is somewhat teleological. The extraordinary fecundity of marine teleosts coupled with their recourse to planktonic larvae may not be primarily concerned with population regulation or distribution. Instead, it may be a solution to the general problem of the nourishment of large predators in an ecosystem that is dominated by micron-scale plants and millimeter-scale herbivores.

This possibility seems to have escaped the attention of general ichthyologists and it was suggested to me by a remarkable — but equally remarkably ignored — contribution by Walter Nellen (1986), who thought that *"bony fish may have evolved to be nourished to some good extent by their children rather than vice versa as it is with other vertebrates "*. A very similar argument has been made by John Caddy (1983) concerning cannibalism in pelagic cephalopods like *Illex*. He suggested that this may be a strategy to bridge gaps in the pelagic particle size spectrum so that the species as a whole is able to exploit food particles too small to be usable by larger, maturing squid.

Nellen (1986) pointed out that a rather simple food chain runs directly from phytoplankton cells, through small crustacean herbivores to small fish, starting with first- feeding larvae. Further, the same food chain may be traced through progressively larger size- classes of teleost fish, via cannibalism. If this analysis is correct, then reproduction in teleosts may not involve — as it does in all other organisms — an energy cost: on the contrary, at least some happy parents may experience an energy gain through reproduction.

This apparently ridiculous suggestion may be evaluated by comparing the energetics of dogfish (*Squalus canis*) and cod (*Gadus morhua*). Large individuals of each species are about one metre in length, but the annual reproductive output of their females is strikingly different: the viviparous dogfish produces 10-15 young in the range 20-25 cm in length while the oviparous cod releases 5-10 million ova, each <2 mm in diameter, batch-spawned over a relatively short season of less than 2 months. If even a tiny fraction of these survive their first year and reach the same life stage as the newborn dogfish, the initial energy expenditure of the female cod has been enormously more effective in terms of potential population increase than that of the female dogfish. Moreover, the tiny cod larvae nourished themselves rather than depending, as did the young dogfish, on a significant maternal contribution to the ovum from which each individual has developed. Subsequently, many small cod contribute nourishment to the adult cod by cannibalism, thus returning to their parent cohorts at least a part of their original maternal energy contribution: individuals that are consumed in this way are <3 years old, after which they appear to become exempt. Cannibalism in cod increases progressively with age, becoming especially characteristic of individuals >100 cm in length.

The instantaneous level of cannibalism by cod depends principally on the relative abundance of small cod in the regional population (Bogstad et al. 1994). When the incoming year-class is unusually strong, many 1-2 year olds will be consumed, as occurred on Flemish Cap in 1991 when a very large class of 1-year old recruits induced a rapid increase in cannibalism by older fish: obviously, events such as this may contribute to a natural, density- dependent mechanism for population regulation, as in the case of the cyclical alternation in relative abundance of adults and young fish that has been observed in the Arcto-Norwegian cod stock.

The same process occurs in the eastern Baltic, where stomach content analysis of more than 60,000 cod over a period of 17 years showed that 25-38% of each incoming 0-group was consumed by adult cod, together with 11-17% of the subsequent 1-group (Link & Garrison 2002); thus, 24% of the post-larval fish of the initial cohort is consumed before it reaches the age of 2 years. Although cannibalism rarely exceeds 20% of the dietary intake of even the largest cod in various North Atlantic regions, in other gadoids (e.g. *Theragra chalcigramma* and *Merluccius* spp.) the overall contribution may be much greater (Neuenfeld & Köster 2000). *Micromesistius poutassou* and *Scomber scombrus* may also be strongly cannibalistic, with as

many as 80% by number of prey items comprising smaller individuals of the same species.

Several authors comment that cannibalism is widespread among teleosts. Reviewing this topic, Smith and Reay (1991) found evidence for cannibalism in 31 families of teleosts and suggested that *"it is considered to be more widespread than this. Finding examples of cannibalism is not difficult, and it may be more interesting to look for taxa in which the behaviour does not take place"*. Unfortunately, it is difficult to ascertain to what extent the characteristic extent of cannibalism differs in different marine habitats, at different depths or in different latitudes.

If, as Smith and Reay (1991) conclude *"the main proximate advantage conferred by cannibalism is assumed to be nutritional"*, then it would be reasonable to suppose that the utility of cannibalism would be greater in low-diversity ecosystems of cold seas. In tropical seas, a wide range of fish species occupies the entire size spectrum from centimetre to metre scale, enabling an efficient transfer of energy from very small to very large species by predation. In cold seas, gaps occur in this size spectrum and these may effectively be filled only by young individuals of the dominant large species.

The very few accounts of cannibalism in tropical environments that I have found conform to this pattern: for instance, although adult *Cynoscion* off Mexico do consume small individuals of their own species, these comprise less than 5% by weight of the adult diet. In tropical tuna, the rate of cannibalsm is not much higher. Finally, it is worth noting that nest- builders may also be filial cannibals, consuming their growing families in the event that other food is scarce: for these fish, reproductive loss is balanced by energy gain.

There is, therefore, plenty of support for Walter Nellen's suggestion that a transfer of energy occurs along a food chain from small to large individuals of many teleost species. For these, we might very well conclude that the function of large incoming year-classes is not to enable rapid population growth, but rather to contribute to the nourishment of the entire adult population by transforming food particles that are too small to be useful to adults (even smaller fish, euphausiids, hyperiids, etc) into items of food (themselves) large enough to be consumed profitably. Elsewhere (Longhurst 1999), I have suggested that perhaps the main function of young gadoids in high latitudes was to nourish their elders and their betters!

So, it is difficult to sustain so easily as we might have done in the old days an assumption that their great fecundity - especially compared with terrestrial mammals and birds - might in some way enable us to take what is wrongly called an annual harvest from their stocks: we can no longer so simply assume that there's plenty more where the ones we took came from.

EFFICIENT OLD FEMALES – A CONSEQUENCE OF THE INDETERMINATE GROWTH OF TELEOSTS

Another aspect of teleost biology that comes to mind in the context of the sustainability of fisheries is their indeterminate growth pattern — from which flows several important consequences for their resilience to fishing pressure: unfortunately, these are negative, in the sense that the apparently inevitable truncation of the older year-classes by any fishery must reduce the ecological efficiency of the stock in relation to the exigencies of its natural habitat. It is easy to forget that the ability to grow throughout life is nothing very special in the living world — it is, in fact, a trait that fish share with the great majority of multicellular organisms from oak trees to jellyfish, and it is associated with a pattern of senescence that is totally foreign to you and me.

Our own pattern of determinate growth — which we share only with other terrestrial mammals, with birds and with some higher insects — means that we do not easily appreciate the consequences of life-long growth. I suggest, however, that we need to think about it very carefully, because it holds both promise and dangers for industrial fisheries. Teleosts, although a highly diverse group, are characterized by indeterminate growth, although the balance between investment in growth and reproduction varies strongly between groups. Among teleosts there is a fast-slow continuum from short-lived and early maturing species (e.g. *Clupea*) to long-lived fish that mature relatively late and spawn larger eggs (e.g. *Sebastes*) (Rochet et al. 2000).

In thinking about the ecological consequences of the teleost growth pattern, what comes first to mind is the ability that it gives to teleosts to respond to an enhanced availability of food by an increase in the rate of growth throughout the life of each individual and not only, as in mammals, during the relatively short period when growth is actually occurring. This response is a factor in the apparently greater sustainability of marine fisheries than of hunting on land. Not so long ago, it was thought to be desirable that a fishery should selectively remove the older, slower-growing individuals to increase the overall productivity of the stock. Unfortunately for this well-worn thesis, it is now understood that the presence of older individuals may be critical to the well-being of a population of teleosts. This is a consequence of the potential immortality of organisms that grow throughout their entire life, and therefore experience negligible senescence, as was suggested by Bidder (1932). Most fish follow this typical pattern, discussed again recently in more realistic terms than those of Bidder by Vaupel et al. (2004) who suggested, in an essay on negative senescence, that *"Youth comes with age"*!

This astonishing statement is based on the fact that indeterminate growth requires that all somatic cells should be capable of active proliferation throughout life, unlike the cells of organisms like you and me. Our own somatic cells have an average age that is close to our chronological age less, say, 20 years: in my own case, my somatic cells have been progres-

sively accumulating errors and inducing senescence for about 60 years now. But organisms with indeterminate growth have a quite different pattern of cell ageing: the somatic cells of a centenarian *Sebastes* are collectively far younger than those of a centenarian man, and they also contain high levels of telomerase, an enzyme required to prevent cell ageing during progressive replication (Klapper et al. 1998). For at least part of their adult lives, the average age of somatic cells in long-lived fish may even become progressively younger as the whole organism ages!

It is only in the terminal phase of their lives that large cod or large rockfish exhibit any sign of senescence, as is also true of tiny tropical freshwater fish that live for no more than 90 days. Others, like Pacific salmon, endure terminal and catastrophic mortality that is not preceded by any period of senescence. The key observation is that delayed senescence in teleosts is associated with the fact that these fish become progressively more "*efficient*" as they age: their natural mortality progressively decreases, their fecundity increases approximately with the cube of their length and, finally, ova and larvae from older females have better survival rates than those from younger fish. Consequently, just a few large, old females have the same reproductive potential as many tens of younger fish and the longer spawning season of old fish increases the probability of a match occurring between larval food requirements and the availability of suitable food items.

We can now be reasonably confident of the generality of the mechanisms involved in these processes: in *Sebastes*, on the west coast, the metabolic endowment (in terms of the size of their oil droplets) received by individual larvae from old females is much greater than the endowment offered by young females to their larvae. Consequently, the survival rate of larvae from old females is significantly higher: a doubling of maternal age translates, approximately into a doubling of time to larval starvation, and to a tripling of larval growth rate. These studies by the late Steve Berkeley and his team (Berkeley et al. 2004) have rightly become classics of the fisheries literature, giving us a good understanding of the mechanisms controlling the survival of teleost larvae. This mechanism, or something very like it, appears to be representative of a wide variety of teleost families, in which older females have higher fecundity, spawn more frequently, and start earlier in the season, spawn larger and more buoyant eggs which have higher fertilization and hatching rates, and which produce larvae that swim faster.

This pattern has now been observed in a wide range of commercial teleosts, very largely in the North Atlantic: cod, haddock, winter flounder, turbot, striped bass, herring and capelin (Trippel et al. 1997). Evidence is accumulating from other species to confirm the generality of the model: for instance, for South Atlantic hake, and species of rockfish other than *S. melanops*.

Clearly the reproductive success of many teleosts is very sensitive to the apparently inevitable truncation of the age structure when they are targeted by a commercial fishery, and this cannot be ignored in evaluating the sustainability of industrial fisheries. In the early years of fishery science in

the North Sea, the age composition of each stock was carefully monitored, although mostly in order to compute stock size from egg and larval surveys (Holt 2008). Apparently, less concern was given later in the 20th century to the truncation of the age structure of a stock by fishing, and that shall be the next problem to be addressed.

TRUNCATION OF THE NATURAL REPRODUCTIVE PERIOD OF EACH YEAR-CLASS

Apart from the reproductive role of older females, the natural longevity of a stock is one of the wider set of characteristics that have evolved to enable it to survive in the variable environment of a particular region of the ocean. This axiom is consistent with the observation that different age structures are characteristic of different parts of each species habitat, and that this structure changes under changing external stresses, such as when a species is invading new habitat.

We observe that age structure of each population takes only a limited range, and will return to the undisturbed state when unusual environmental stress is removed. Lotka discussed this limitation in 1925: *"Now, age distribution is indeed variable, but only within restricted limits. Certain age distributions will practically never occur... There is, in fact, a certain stable age distribution about which the actual age distribution varies, and towards which it returns if through any agency disturbed therefrom"* . Truncation of the age structure is a very strong violation of ecosystem balance, yet the extent to which some populations have been truncated by fishing, even right under the noses of apparently competent fish stock managers, is quite remarkable. Perhaps the most blatant example in the fisheries literature is the 30-year regression of older fish in the 2J3KL cod stock of the Canadian Atlantic area. Both the maximum age of females in the population, and also the age at which they achieved maturity were reduced by 50% between 1962 and 1992 partly due to changing environmental conditions but also to the offshore trawl fisheries: high-lining and discarding were rife during this period.

Generally, after several decades of intensive trawling, none of the larger species in a fishery retains an age distribution that is appropriate to the exigencies of the natural environment (Stearns 1976). In cold seas, a population age structure will be evolved in this way that would be more appropriate for a fish in warm seas — but with one important difference: as in the 2J3KL cod, only a few of their older year-classes will be mature. In ecosystems that have been modified in this way, few individual species may retain enough reproductive competence for continued survival and the ecosystem itself may become seriously unbalanced.

The relationship between the natural length of life of a species and the variability of its annual recruitment was well known to the early fishery scientists. Those who worked on the problems of the herring fisheries

were more concerned with the elusive spawner/recruitment relationship while those studying demersal fish were more interested in the survival of spawners in the adult population (Holt 2008). It was Garth Murphy (1967) who first published observations to demonstrate that among groups of related species, those with the most variable recruitment had the greatest longevity; he explicitly suggested that such species needed to maintain a reproductive population over a longer period than congeners living in more stable environments.

Using the late Ransom Myers' data-base of recruitment in 250-odd stocks, it is easy to demonstrate that longevity responds principally to recruitment variability rather than to latitude and that the Murphy relationship described above holds among about 75 clupeid stocks, rather than his original 5 - and also in other groups as diverse as gadoids (68 stocks) and scombroids and tuna (18 stocks): only flatfish appear to be exceptional, for reasons easily understood from the manner in which they settle into their characteristic habitat after larval life (Longhurst 2002).

In a population with a pristine age distribution, each cohort maintains a hypothetical fecundity level that remains almost unchanged from first maturity through to the very last years of life — over, that is, a period of 15-20 years — even as their numbers are progressively reduced by natural mortality. There is thus a simple relationship between the extent to which longevity is reduced by fishing and the period over which a dominant year-class is able to continue to produce ova at an almost constant rate (Longhurst 1999).

Here, then, is a second reason to suppose that the progressive loss of older fish in the population is likely to reduce the success of a fished stock. If industrial fishing so modifies stocks that the surviving females are able to produce only less-than-normally successful larvae, and only over a shorter-than-normal period of years, then it is very difficult to be optimistic about the sustainability of the enterprise.

CONCLUSIONS

I have no illusions that this short essay has actually shed any light on the truth or otherwise of the axiom that their surplus production is offered to us by the marine ecosystems. But I hope that I may at least have reminded my readers of the depth of our ignorance about the functioning of marine ecosystems, and how little we know about the life history parameters of marine fish. The extent of our inability to predict future states - or even to specify instantaneous states - of fishery ecosystems appears to be very largely ignored by those who are presently planning for the future of fish stock management. It seems to be assumed that if information or understanding is needed, it will be available; the paucity of descriptive data, and the depth of our ignorance of biological processes, is little discussed.

Exactly who started the stampede towards ecosystem-based fishery management doesn't matter, but his or her success has been astonishing. Nor does it matter that many people have emphasised that the term

doesn't really mean what it seems to mean, and that all that is implied is the recognition that both physical and biological environmental variability have consequences for stock status. One still reads bizarre statements - such as this gem that I found in a University of Miami forum of 2004: *"Ecosystem-based fishery management (EBFM) is a new direction for fishery management, essentially reversing the order of management priorities to start with the ecosystem rather than the target species"*.

It is astonishing to what extent organizations like FAO, NOAA and DFO have developed and embraced unproven approaches like EBFM and to what extent EBFM is formalized in policy statements, and even in international agreements. The assumptions about what may be possible are breath-taking. It is for that reason that I suggest that simple "selective conjectures" such as the assumption of surplus production from fish stocks, should be examined very carefully at the present time.

Perhaps fisheries scientists should be spending as much time thinking about their fundamental assumptions as they currently do in thinking about how their management procedures could be fixed. I offer for their further consideration, without any comment on my part, the ecological concept of population regulation, which is - and always has been - a necessary axiom of fishery science. Yet density-dependent population regulation, according to ecologist Barryman in 2002, had been described in the previous 15 years or so as a *"bankrupt paradigm", "a monumental obstacle to progress", "a mind-set, a dogma, a faith"*, without "*emerging consensus*" and lacking "*widespread evidence*" for its existence. He concludes that population regulation is really nothing more than a descriptive term for one of the emergent properties of population dynamics, that may or may not be exhibited by some natural populations, but not by others, and according to varying circumstances...

No wonder, then, that Sidney Holt (who, after all, helped to write the book on fishery science) suggested in 2006 that he had spent most of his life "*opposing the hubris of managing the ocean and its contents: a losing battle, I'm afraid...*".

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REFERENCES

Berkeley SA, Chapman C, Sogard SS (2004) Maternal age as a determinant of larval growth and survival in a marine fish *Sebastes melanops*. Ecology (Wash DC) 85:1258-1264

Bidder GP (1932) Senescence. Brit Med J 1932:583-585

Bogstad B, Lilly GR, Mehi S, Pálsson ÓK, Stefánsson G (1994) Cannibalism and year-class strength in Atlantic cod in Arcto-boreal ecosystems. ICES Mar Sci Symp 198:576-599

Barryman, AA (2002) Population regulation, emergent properties and a requiem for density dependence. Oikos 99:600-606

Caddy JF (1983) The cephalopods: factors relevant to their population dynamics. FAO Fish Tech Pap 231:1-452

CALCOFI (2007). CALCOFI Reports 47, 2007

Chadwick EMP, Brodie W, Colbourne E, Clark D, Gascon D, Hurlbut T (2007) History of annual multi-species trawl surveys on the Atlantic coast of Canada. Atlantic Zone Monitoring Program (AZMP) Bull 6:25-42

Cury P, Shannon L, Shin Y-J (2001) The functioning of marine ecosystems. FAO Reykjavik Conf Resp Fish Mar Ecosyst Doc 13:1-22

Cushing DH (1981) Temporal variability in production systems. In: Longhurst AR (ed) Analysis of marine ecosystems. Academic Press, London, p 443-472

Dunne JA, Williams RJ, Martinez ND (2004) Network structure and robustness of marine food webs. Mar Ecol Progr Ser 273:291-302

Frank KT, Petrie B, Choi JS, Leggett WC (2005) Trophic cascade in a formerly cod-dominated system. Science 308:1621-1623

Froese R, Luna S (2004) No relationship between fecundity and annual reproductive rate in bony fish. Acta Ichthy Pescat 34:11-20

Holt S (2006) The notion of sustainability. In: Lavigne DM (ed) Gaining ground: in pursuit of ecological sustainability. International Fund for Animal Welfare, Guelph, Ont, p 43-81

Holt SJ (2008) (FAO retired, Paciano, Italy) Personal communication

Klapper W, Heidorn K, Kühne K, Parwaresch R, Krupp G (1998) Telomerase activity in 'immortal' fish. FEBS Letters 434:409-412

Link JS, Garrison LP (2002) Trophic ecology of Atlantic cod on the NE US continental shelf Mar Ecol Progr Ser 227:109-123

Longhurst A (1999) Does the benthic paradox tell us something about surplus production models? Fish Res (Amst) 41:111-117

Longhurst A (2002) Murphy's Law revisited: longevity as a factor in recruitment to fish populations. Fish Res (Amst) 56:125-131

Murphy G (1967) Vital statistics of the California sardine and the population consequences. Ecology (Wash DC) 48:731-735

Nellen W (1986) A hypothesis on the fecundity of bony fish. Meeresforsch (Hamburg) 31:75-89

Neuenfeld S, Köster FW (2000) Trophodynamic control of recruitment success in Baltic cod: the influence of cannibalism. ICES J Mar Sci 37:300-309

Pauly D (2005) An ethic for marine science. Newsletter - Sea Around Us Project 32:1-4

Pepin P, Petrie B, Therriault J-C, Narayanan S and 10 others (2005) The Atlantic Zone Monitoring Program (AZMP): Review of 1998-2003. Can Tech Rep Hydrog Ocean Sci 242:v+87p

Rochet M-J, Cornillon P-A, Sabatier R, Pontier D (2000) Comparative analysis of phylogenetic and fishing effects in life history patterns of teleost fishes. Oikos 91:255-270

Smith C, Reay P (1991) Cannibalism in teleost fish. Rev Fish Biol Fish 1:41-64

Stearns SC (1976) Life history tactics: a review of the ideas. Am Nat 108:783-790

Trippel EA, Kjesbu OS, Solemdal P (1997) Effects of adult age and size structure on reproductive output in marine fishes. In: Chambers RC, Trippel EA (eds) Early life history and recruitment in fish populations. Chapman & Hall, New York, p 31-62

Vaupel JW, Baudisch A, Dolling M, Roach DA (2004) The cause for negative senescence. Theor Popul Biol 65:339-351

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SQUALENE IN NOVA SCOTIAN DEEP-SEA SHARKS AND IN THE PACIFIC EULACHON

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The occurrence of the hydrocarbon, squalene, in diverse marine organisms is not uncommon, but quantities of commercial interest are generally limited to the livers of a few members of the shark family. Nova Scotia shallow-water dogfish lack this component in their liver oil. An opportunity to compare several liver oils from deep-water exploratory catches, however, yielded diverse results, confirming its presence in deeper water species. A Pacific eulachon fish body oil rich in squalene was analysed also and the results were compared with the oils from deep sea sharks.

Il n'est pas rare de trouver l'hydrocarbure squalène dans divers organismes marins, mais ce n'est généralement que dans les foies de quelques membres de la famille des requins qu'on le trouve en quantités d'intérêt commercial. Cet hydrocarbure n'est pas présent dans l'huile de foie des aiguillats des eaux peu profondes de la Nouvelle-Écosse. Toutefois, les résultats divers d'une comparaison de plusieurs huiles de foie de poissons provenant de prises exploratoires en eaux profondes confirment la présence de cet hydrocarbure dans des espèces vivant à de plus grandes profondeurs. De l'huile de poisson riche en squalène qui provenait d'un eulakane du Pacifique a également été analysée et comparée aux huiles des requins d'eaux profondes.

INTRODUCTION

A considerable interest in deep-sea shark liver oils has developed in recent years (Summers et al. 1990, Bakes & Nichols 1995, Bordier et al. 1996, Borch-Jensen et al. 1997, Deprez et al. 1970), as well as in shallow water species (Jayasinghe et al. 2003). This type of work is stimulated by a commercial demand for squalene. As the name suggests, squalene was originally isolated from shark liver oil. Our most common Nova Scotian shark species, the shallow-water dogfish *Squalus acanthias* Linnaeus 1758 regrettably, has very little or no squalene in its liver oil. We had an opportunity to examine the liver lipids of a western Atlantic deep-sea shark, also of the family Squalidae, the black dogfish *Centroscyllium fabricii* (Reinhardt) 1825. Livers of the deep-sea cat shark *Apristurus profundorum* (Goode & Bean) 1896 and rough sagre *Etmopterus princeps* Collett 1904 were also provided for research, as was a single liver (274 g) from a deep-sea cartilaginous fish, the longnose chimaera *Harriota raleighana* Goode & Bean 1895, order Chimaeriformes, family Chimaeridae. These were all caught in a commercial exploration using traps set near Nova Scotia in approximate depths of 1000 m or more. For comparison of fish body squalene an earlier study in the west coast euryhaline fish, usually referred to as "eulachon,"

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was repeated on a small scale as new analytical technology (Iatroscan Thin Layer Chromatography/Flame Ionization Detection [TLC/FID]) was available to aid in these analyses, along with fractional crystallization (Nenadis & Tsimidou 2002), a new technique remarkably faster than some proposed liquid handling procedures requiring days.

SAMPLES AND METHODS

The black dogfish (NS-1) were caught about June 11, 1995 in traps and the fish put on ice. Livers were removed after 9 days. The chimaera was caught June 13 and the liver removed after 7 days of being held on ice. The second lot of black dogfish and all other samples were caught in August and were handled similarly. The livers were delivered on ice to the CIFT laboratory from the National Sea Products Ltd. plant in Lunenberg, Nova Scotia in plastic bags with no information other than the species designation. As a first step the livers were sorted and compared, and any that appeared abnormal for colour or consistency were excluded. The appropriate livers were homogenized and extracted by the method of Bligh and Dyer (1959) and the lipid examined for Wijs iodine value and % unsaponifiables by AOCS methods Cd-1-25 and Ca-66-53 respectively.

Lipid composition by Iatroscan TLC/FID was performed with an Iatroscan TH-10 analyzer equipped with a flame ionization detector attached to a SP4200 computing integrator (Spectra Physics) in order to give digital integration of the peaks. The FID hydrogen flow rate was 160mL min^{-1}. The samples were chromatographed on Chromarods S-III developed in hexane:diethyl ether:formic acid (97:3:1 v/v/v) for 55 min. The solvents were allowed to evaporate from the rods in an oven for 2 min at 110°C prior to scanning with the FID of the Iatroscan TH-10 analyzer.

The black dogfish liver lipid extract was applied to a TLC plate and separated into two major bands with hexane:diethyl ether:acetic acid (85:15:1 v/v/v). The recovered 1-*O*-alkyl-diacylglycerol and triacylglycerols were converted to methyl esters with BF_3-MeOH.

For the fatty acid methyl esters (FAME) a modified AOCS Official Method Ce 1b-89 was applied to lipids or lipid fractions by heating 20 mg in methanol containing 4% BF_3 at 100°C for 1 h. The FAME were recovered in hexane and analyzed by GLC (gas-liquid chromatography). The column was Omegawax-320, 30 m x 0.32 mm id installed in a Perkin Elmer GC model 8420 equipped with a split injection port and a FID. The program used for GLC of FAME was: initially 185°C for 8 min, a ramp of 3°C min^{-1} to 230°C, and held for 10 min.

RESULTS AND DISCUSSION

Shark Lipids

Sharks are a well-known and prolific fish family, including very large fish with unpopular habits such as attacking shipwrecked sailors. They are

found mainly in a broad band of waters on each side of the equator, but at least some members of the dogfish family are found in the cold waters of the North Atlantic and Pacific oceans. Public interest has stemmed not from shark liver oils, but from a small book rashly promising good health in respect to shark cartilage for treating cancer and degenerative diseases (Lane & Comae 1992). Possible use of these oils in skin creams has also been discussed.

The commercial demand for shark liver oil (Summers et al. 1990) is based on the use of squalene, a $C_{30}H_{50}$ hydrocarbon with six *trans* ethylenic bonds (2,6,10,15,19,23-hexamethyl-2,6,10,14,18,22-tetracosahexaene) (Fig 1).

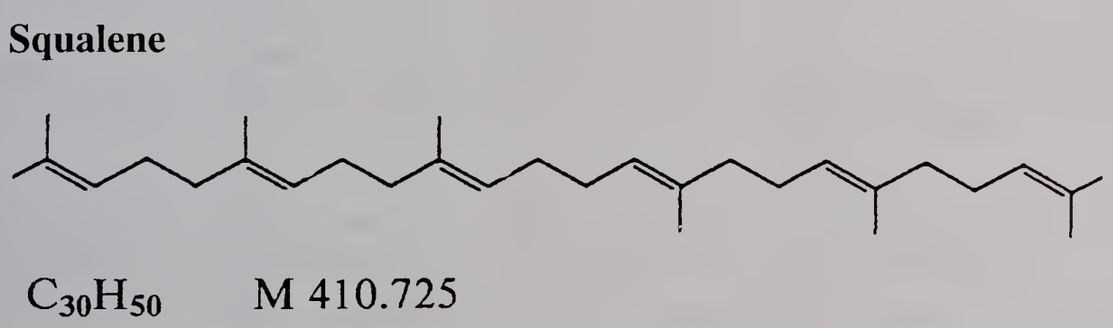

Fig 1 Squalene

This hydrocarbon is not rare as it is 0.1-0.7% of olive oil and is in a few other vegetable seed oils such as amaranthus grain (He et al. 2002), as well as in some marine organisms. Squalene itself will oxidize spontaneously, but after hydrogenation to squalane is useful as a stable lubricant. Recovery and refining on an industrial scale is discussed by Summers et al. (1990). It has a low density (0.866 at 5°C) which sharks themselves may find useful in moving from the surface to considerable depths, as discussed in some detail by Nevenzel (1989) and Morris and Culkin (1989).

Shark Lipid Analyses

The graphic area percentages for major lipid classes (Table 1) for TLC-FID are only an approximation of the neutral lipid classes, but these should have similar relative responses once separated and moved along the Chroma-rod. This quartz rod coated with silica gel is passed through an ionization flame detector. An alternative way to quickly assess the squalene content of a fish liver oil is simply to transesterify the oil and analyse the resulting solution of fatty acid methyl esters and squalene on a polyglycol-based capillary gas-liquid chromatography column. We have used both SUPEL-COWAX-10 and Omegawax-320 for this purpose, these being commonly in use for the highly unsaturated and long-chain polyunsaturated fatty acids of marine lipids. Owing to the diverse numbers of ethylenic bonds of FAME (either n-3 or n-6, counting to the first bond from the terminal methyl group[1])

1 There are varied nomenclatures for fatty acids: e.g. 18:2Δ9, Δ12, refers to an 18 carbon fatty acid, with 2 cis double bonds between carbons 9 &10 and 12 & 13, but 18:2n-6 is far simpler.

Table 1 Bligh and Dyer liver extract lipids, properties and proportions from TLC-FID.

	Black dogfish			Deep-sea cat shark	Rough sagre	Chimaera
	NS-1	NS-2	USSR*			
Lipid content (w/w %)	82.6	83.8	73.2	84.1		85.6
Iodine value	90.2	93.7	286	89.0		86.6
Unsaponifiables (w/w %)	61.9	37.0	79	37.7		28.4
Iatroscan lipid classes (area percent)						
Triacylglycerol	9.4	10.7	-	55.9	16.8	6.3
Diacylglycerol ether	69.2	73.0	-	3.1	54.8	84.3
Hydrocarbon	18.5	13.4	-	36.2	27.5	Nil
Sterol	1.0	0.8	-	2.3	0.9	0.1
Polar Lipid	0.9	1.2	-	2.3	1.0	0.8
Sterol (wax) Ester	1.0	1.0	-	0.4	0.1	trace

*Data from Dolbish et al. 1969

chain length overlaps often occur. With our program the squalene fell on or just after the 24:1n-9 position, both just after the 22:6n-3 position. Since squalene is chemically different from the methyl esters of fatty acids this position could vary with the temperature program as well as the polarity of the column. The black dogfish oil FAME chromatograms from both samples were remarkable in showing a series of saturated (16%) and monoethylenic (73%) peaks, with almost no significant polyunsaturated fatty acid (PUFA) peaks (Table 2), and then a large squalene peak consisting of ~20% of the total peak area. The monoethylenic fatty acid pattern of the black dogfish liver oil was very conventional and similar to that of herring oil or *S. acanthis* liver oil (Kang et al. 1996). The chimaera liver oil showed no squalene but the FAME gas liquid chromatography analysis showed an unknown peak (8% of FAME area) immediately preceding the 20:0 position. It also had an unusual monoethylenic fatty acid pattern with n-7 fatty acids being extended from 16:1n-7 through 18:1n-7 to 20:1n-7 and similarly 20:1n-9 was extended to 22:1n-9 (Table 2).

The high iodine value in the Russian report (Dolbish et al. 1969) on the liver oil of black dogfish is a firm indicator of squalene as the dominant lipid in their sample. The calculated iodine value (IV) of squalene is 370 and is an example of the effect of squalene inclusion in fish lipids, the addition of 10% squalene to seal oil revised the IV from 152 to 183. It is possible to use the saponification method of Kovacs et al. (1979) with cholestane added to any suitable oil or lipid fraction as an internal standard for GLC determination of squalene. On the polyglycol-based gas-liquid chromatography columns the cholestane emerged immediately after the squalene but with cleanly separated peaks.

The deep-sea cat shark is a small (≤60 cm) shark regarded as a pest when attempts are made to trap other sharks with commercial potential such as the black dogfish. The total liver lipid when transesterified and analysed for FAME included the squalene peak. The fatty acids (Table 2) were not of remarkable interest. A shoulder presumed to be 18:1n-11 is included

Table 2 Fatty acids of different liver lipid samples

	Black dogfish			Deep-sea cat shark	Chimaera
	Total Oil	TAG	DAGE	Total Oil	Total Oil
14:0	1.4	2.5	1.0	2.3	1.0
16:0	12.3	13.3	13.8	8.9	10.5
18:0	1.0	1.5	1.0	1.1	4.5
Total	*16.2*	*19.0*	*17.3*	*12.3*	*19.4*
16:1n-7	3.9	6.3	2.8	6.6	4.7
18:1n-9	23.7	19.5	27.5	22.6	25.5
18:1n-7	3.0	3.2	3.0	4.0	9.1
20:1n-11	2.0	1.0	1.1	4.9	1.9
20:1n-9	13.1	16.0	13.8	13.5	3.3*
20:1n-7	0.9	1.0	0.9	0.9	3.6
22:1n-11+13	21.4	19.6	22.9	16.7	1.9
22:1n-9	3.8	3.4	4.0	4.6	2.1*
22:1n-7	0.7	0.5	0.4	2.3	0.7
Total	*73.2*	*72.2*	*78.3*	*76.1*	*58.9*
18:2n-6	0.7	0.7	0.8	1.0	0.7
18:3n-3	0.2	0.3	0.2	0.5	0.2
18:4n-3	0.4	0.3	0.2	0.1	0.1
20:4n-6	0.3	0.5	0.1	0.3	1.0
20:5n-3	0.8	0.6	0.2	2.9	1.3
22:5n-3	0.6	1.5	0.1	1.1	0.5
22:6n-3	2.7	1.8	1.0	4.1	2.0
Total PUFA	*10.7*	*9.5*	*4.7*	*9.9*	*13.5*
Calc. IV	94	86	75	93	92

*Confirmed by mixed analysis with canola oil FAME.

in 18:1n-9, and this correlates with a prominent peak for 20:1n-11. This is suggestive of chain shortening from an original source of 22:1n-11 in the diet (Ackman et al. 1980). Although 18:1n-11 could not be discerned in the GLC analysis of the chimaera liver oil a high proportion of 20:1n-11 relative to 20:1n-9 was also apparent in this species. Thus conversion from 20:1n-11 could also account for the relatively high 22:1n-11 already mentioned. It would seem paradoxical to have n-9 fatty acids going to longer (20:1) chain lengths and then elongation favouring n-11, but 22:1n-11 is common in most fish oils.

The cat shark liver lipid extract showed (Table 1) an even greater proportion of squalene (36%) than did the black dogfish liver oil. The gas liquid chromatography confirmed the hydrocarbon to be squalene. Since the triacylglycerols were just over half of the total lipid the diacylglycerol ethers were only present in trace amounts. The rough sagre is also small, with 75 cm being the maximum length (Scott & Scott 1988). The liver oil of this species was dominated by diacylglycerol ethers but had nearly 30% squalene.

Nova Scotia and other Atlantic provinces could benefit from more deep-sea exploration as there is evidence that deep-sea and northerly teleost fish may also provide squalene in their lipids (Hayashi & Kishimura 2003).

The structure of traditional fisheries in this area limits various fisheries to certain times of the year, so deep-sea fisheries could provide additional work periods. In a parallel situation in Tasmanian waters, Deprez et al. (1990) have suggested that these novel resources may be limited.

Eulachon Lipids

The shark species described here are not "monsters of the deep," typically being 100 cm or less (Scott & Scott 1988). Strangely, Canada has a much smaller bony fish that is also rich in squalene. The teleost eulachon *Thaleichthys pacificus* Richardson, 1836, matures at 108 mm and the adults in spawning runs of the Fraser River are only 140-150 mm in length (Hart 1973). It is an anadromous vertebrate of the smelt (Osmeridae) family. The fish are found in western North America from the Russian River of California to the eastern Bering Sea. That it is an oily fish has been long known; the dried fish burned so readily when fitted with a wick that it came to be known as the candlefish. The oil was reputedly solid at room temperature and was collected and traded by the coastal Indians of British Columbia across the Rocky Mountains to the Indians of the Great Plains. In 1968 a few eulachon were collected personally by the author (R.G. Ackman) from a shrimp trawl in Barkley Sound, Vancouver Island. The head and gutted bodies contained 21% lipid of which 84% was triacylglycerols, 3.1% was polar lipid (primarily as phospholipid) and 12% squalene (Ackman et al., 1968). This lipid class analysis was carried out by planar TLC with the squalene confirmed by GLC, and was an unexpected finding. At various times when interest in squalene arose the attempts to develop commercial fisheries were refused by various governmental agencies on the ground that these fish were reserved for Indian use and were needed to support other and more lucrative fisheries.

A more recent capture of eulachon actually taken in the Fraser River, possibly post-spawning, showed only a small amount of squalene (10%) in the lipid, 13.5% of the body and head. The strange feature of the body/head lipids of this lot of eulachon was the fatty acid compositions of the triacylglycerols. Those of the polar lipids were normal for marine fish with respect to the content of long-chain polyunsaturated fatty acids, but the triacylglycerols separated by planar TLC were dominated by very high proportions of 14:0 (9%), 16:0 (20%), 16:1 (7%), 18:0 (5%) and especially high-melting (44°C) vaccenic acid, which is *trans*-18:1n-7, at 4%. Isoprenoid fatty acids (e.g. pristanic) were also present. These observations reinforce the classical description of the oil of the fish taken in freshwater as "solid at ordinary temperatures" (Hart, 1973). These proportions of high-melting fatty acids are in accord with those reported by Kuhnlein *et al.* (1996), using the alternative fish name "ooligan" and basically was a nutritional study of a traditional food fat of the British Columbian indigenous cultures. Neither it nor the similar work of Kuhnlein and Chan (1998) considered squalene, although it would be a normal content of the traditional "grease." The role of squalene in this species may be to dilute and reduce the viscosity or

melting point of these triacylglycerols in the marine life phase in their cold ocean water life phase.

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REFERENCES

Ackman RG, Addison RF, Eaton CA (1968) Unusual occurrence of squalene in a fish, the eulachon *Thaleichthys pacificus*. Nature 220:1033-1034

Ackman RG, Sebedio J-L, Kovacs MIP (1980) Role of eicosenoic and docosenoic fatty acids in freshwater and marine lipids. Mar Chem 9:157-164

Bakes MJ, Nichols PD (1995) Lipid, fatty acid and squalene composition of liver oil from six species of deep-sea sharks collected in southern Australian waters. Comp Biochem Physiol 110B:267-275

Bligh EG, Dyer WJ (1959) A rapid method of total lipid extraction and purification. Can J Biochem Physiol 37:911-917

Borch-Jensen C, Magnussen MP, Mollerup J (1997) Capillary supercritical fluid chromatographic analysis of shark liver oils. J Am Oil Chem Soc 74:497-503

Bordier CG, Sellier N, Foucault AP, Le Goffic F (1996) Purification and characterization of deep sea shark *Centrophorus squamosus* liver oil 1-*O*-alkylglycerol ether lipids. Lipids 31:521-528

Deprez PP, Volkman JK, Davenport SR (1990) Squalene content and neutral lipid composition of livers from deep-sea sharks caught in Tasmanian waters. Aust J Mar Freshwater Res 41:375-387

Dolbish GA, Teplitskaya AM, Bochkareva VG, Konysheva LM, Nikitina IN (1969) Vitamin content of the liver of some Pacific sharks. Rybnoe Khozyaistvo No 5 Moskva: 60-62

Hart JL (1973) Pacific fishes of Canada. Fisheries Research Board of Canada, Ottawa, Bulletin 180

Hayashi K, Kishimura H (2003) Amount of squalene and fatty acid composition of triacylglycerols and phospholipids in flesh and liver lipids of some deep-sea teleost fish, morid cods and whiptails. J Oleo Sci 52(7):339-345

He P-H, Cai Y, Sun M, Corke H (2002) Extraction and purification of squalene from amaranthus grain. J Agric Food Chem 50:368-372

Jayasinghe C, Gotoh N, Tokairin S, Ehara H, Wada S (2003) Inter species changes of lipid compositions in liver of shallow-water sharks from the Indian Ocean. Fish Sci 69:644-653

Kang S-J, Lall SP, Ackman RG (1997) Digestion of the 1-*O*-alkyl diacylglycerol ethers of Atlantic dogfish liver oils by Atlantic salmon *Salmo salar*. Lipids 32:19-30

Kovacs MIP, Anderson WE, Ackman RG (1979) A simple method for the determination of cholesterol and some plant sterols in fishery-based food products. J Food Sci 44(5):1299-1305

Kuhnlein HV, Yeboah F, Sedgemore M, Sedgemore S, Chan HM (1996) Nutritional qualities of ooligan grease: a traditional food fat of British Columbia first nations. J Food Comp Anal 9:18-31

Kuhnlein HV, Chan HM (1998) Ooligan grease: a traditional food fat of western Canada and Alaska. Int J Circumpolar Health 57(Suppl I):211-214

Lane IW, Comae L (1992) Sharks don't get cancer. Avery Publishing Group Inc, Garden City Park, New York

Morris RG, Culkin F (1989) Chapter 13: Marine biogenic lipids, fats, and oils. In: Ackman, RG (ed) Marine biogenic lipids, fats and oils, Vol 2. CRC Press, Boca Raton, Fla, p 158-160

Nenadis N, Tsimidou M (2002) Determination of squalene in olive oil using fractional crystallization for sample preparation. J Am Oil Chem Soc 79(3):257-259

Nevenzel JC (1989) Chapter 1: Biogenic hydrocarbons of marine organisms. In: Ackman, R.G. (ed) Marine biogenic lipids, fats and oils, Vol 1. CRC Press, Boca Raton, Fla, p 3-71

Scott WB, Scott MG (1988) Atlantic fishes of Canada. Can Bull Fish Aquat Sci 219

Summers G, Wong R, Eyres L (1990) Handling and processing shark livers for the recovery of squalene and diacyl glyceryl ethers. Department of Scientific and Industrial Research, Private Bag, Auckland, New Zealand, DSIR Crop Research Seafood Report No 1

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ASSESSMENT OF ENVIRONMENTAL CONDITIONS IN SYDNEY HARBOUR, NOVA SCOTIA: GENERAL INTRODUCTION

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The Sydney steel works and its associated coking plants discharged large quantities of chemical pollutants into the local environment for 100 years from the beginning of steel and coke production in 1901 until the final shut-down of the steel plant in 2001. The coking operation, which was responsible for a large fraction of the atmospheric discharge of polyaromatic hydrocarbons (PAHs) and other chemicals, was phased out somewhat earlier between 1981 and 1988. Contaminant inputs to the atmosphere from steel mill and coke oven smokestacks decreased from the early 1980s until 2001 as first the coke ovens and then the steel plant ceased production. The same cannot be said about contaminants discharged to the aquatic environment. Aqueous discharges from the site were funneled through Coke Oven Brook to the Sydney Tar Ponds, an area at the head of the estuarine portion of Muggah Creek that was dammed off to form a contaminant holding facility (see Fig 1). Large quantities of sediments contaminated with hydrocarbons as well as polychlorinated biphenyls (PCBs) and heavy metals accumulated in the Tar Ponds as well as in Muggah Creek. Because the Tar Ponds are not isolated from natural freshwater runoff, runoff water (and contaminants) continues to flow through the Tar Ponds into Muggah Creek and Sydney Harbour. In addition to these inputs directly related to the steel plant, the South Arm of Sydney Harbour receives municipal and industrial discharges of a city of approximately 24,000 people (2001 census). One of the main sewers discharges into Muggah Creek.

A large engineering project is underway in the city of Sydney to remediate chemical contamination in the area of Coke Oven brook, the Tar Ponds and Muggah Creek. In this project large quantities of contaminated sediments will be removed, others immobilized and capped, and the freshwater flow and existing sewage discharges into Muggah Creek channeled to the Harbour through a new uncontaminated channel bed. The project is described on the Sydney Tar Ponds Agency website (http://tarpondscleanup.ca). The project, identified on this website as 'the most prominent remediation project in Canada', has undergone extensive and sometimes controversial environmental review and includes monitoring of environmental conditions in Sydney Harbour.

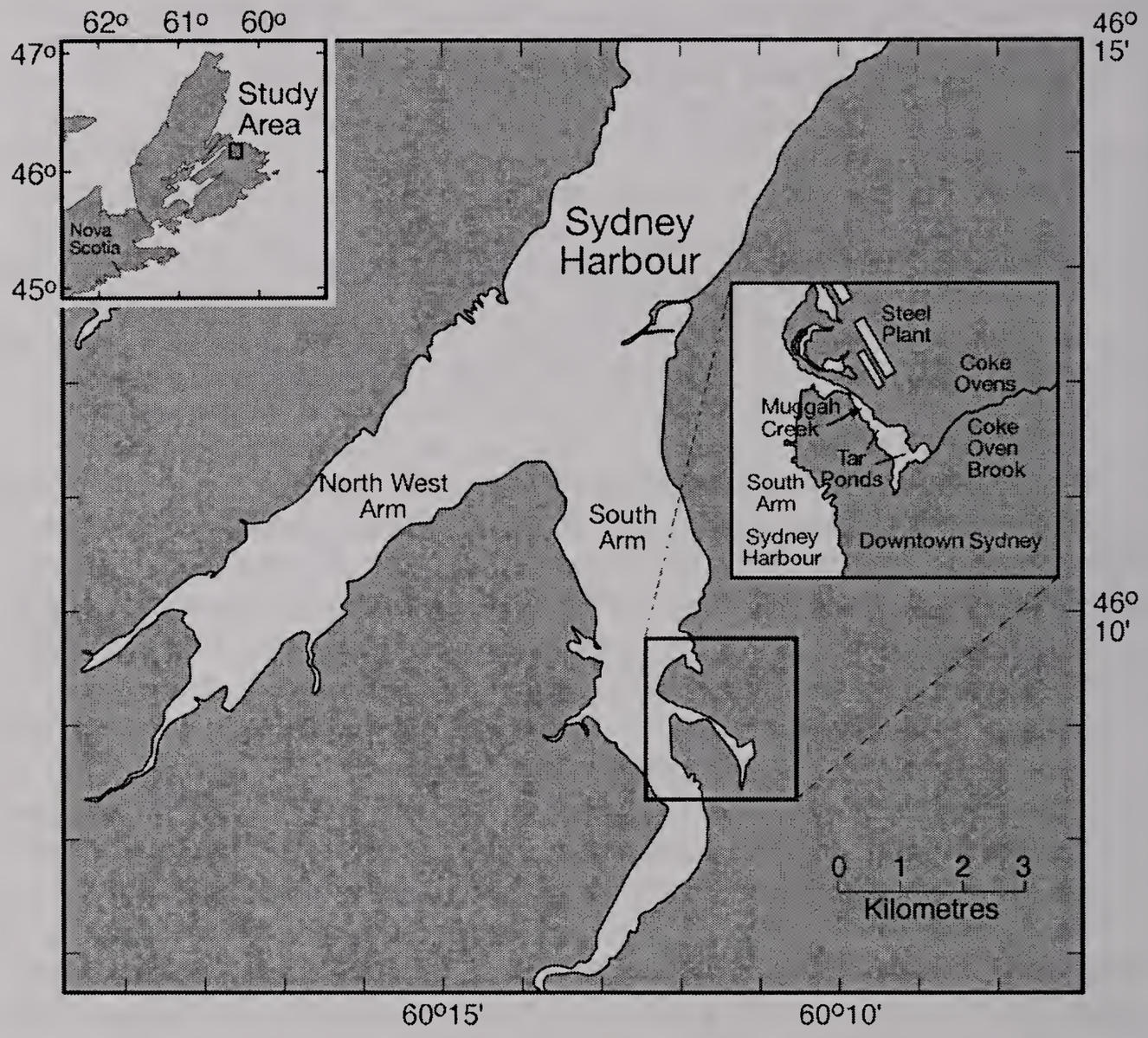

Fig 1 Relative locations of Sydney, Sydney Harbour, Muggah Creek, Coke Oven Brook, the Sydney Steel Plant, the Coke Ovens and the Tar Ponds.

A team of scientists from the Department of Fisheries and Oceans, Environment Canada, the National Research Council, and Dalhousie and Trent Universities recently completed an extensive assessment of environmental conditions in Sydney Harbour, environmental effects of contaminants and potential for remediation of contaminants in the Harbour (Lee 2002). The focus was the chemical contamination of the Harbour with hydrocarbons, PCBs and heavy metals much of which would have originated from the Sydney Steel Plant. The project was funded by the Toxic Substances Research Initiative (TSRI), of Health Canada, which provided among other things, research funding for understanding the impacts of toxic chemicals discharged to the environment on ecosystem and human health. The timing of the field work for this project (1999-2002) was ideal from the perspective of providing an up-to-date assessment of environmental processes and conditions in the Harbour immediately before the commencement of planning for the Tar Ponds clean-up project in 2004.

The TSRI project was a multidisciplinary investigation of physical water circulation, contaminant distributions in water and surficial sediments, time

series inventories of contaminants in sediments, and biological effects of contaminants in the sediments including changes in community structure and function. It also included components that investigated microbiological processes controlling the biodegradation of contaminants in sediments and developed predictive mass balance models for the transport of contaminants through the Harbour. Two graduate student theses have been based on this work (Ethier 2002, Querbach 2002), and a number of technical reports have been published (Ernst et al. 1999, Holstead & Mackay 2000, Petrie et al. 2001, Stewart et al. 2001, Stewart et al. 2002). Papers on the results of this research are now appearing in the literature (Fortin et al. 2003, Tay et al. 2003) including three papers being published in this issue of the Proceedings of the Nova Scotian Institute of Science. The first of these by Loring et al., describes geochemical and environmental processes controlling the distribution of heavy metals in surficial sediments; the second by Yeats and Dalziel, the geochemistry of heavy metals in the water column; and the third by King, the contamination of sediments and lobster by PAHs and associated human health risks from consumption of lobster tomalley. In the next issue of the Proceedings, we hope to publish several more articles relevant to the continuing interest in the clean-up of Sydney Harbour, including ones on water circulation and mixing and modeling of water quality.

REFERENCES

Ernst B, Pitcher D, Matthews S, Julien G (1999) Concentrations and distribution of polycyclic aromatic hydrocarbons (PAHs), PCBs and metals in sediments, mussels (*Mytilus edulis* and *Modiolus modiolus*) and lobsters (*Homarus americanus*) from Sydney Harbour, Nova Scotia. Environment Canada (Atlantic Region), Surveillance Report EPS-5-AR-99-7

Ethier ALM (2002) A review and mass balance model of the sources and fate of polycyclic aromatic hydrocarbons in Sydney Harbour, Nova Scotia. MSc thesis, Environmental Engineering, Trent University, Peterborough, ON

Fortin N, Beaumier D, Lee K, Greer CW (2003) Soil washing improves the recovery of total community DNA from polluted and high organic content sediments. J Microbiol Methods 56:181-191

Holstead AL, Mackay D (2000) Development of a multi-QWASI model to simulate fate of PAHs in Sydney Harbour, Nova Scotia (operationsl manual for distribuytion to potential users). Report to Department Fisheries and Oceans, Maritimes Region, Dartmouth, NS

Lee K (2002) Environmental effects and remediation of contaminants in Sydney Harbour, Nova Scotia. Final report to Health Canada for Toxic Substances Research Initiative (TSRI) Project #93

Petrie B, Bugden G, Tedford T, Geshelin Y, Hannah C (2001) Review of the physical oceanography of Sydney Harbour. Can Tech Rep Hydrog Ocean Sci 215

Querbach K (2002) Impacts of coal-generated polycyclic aromatic hydrocarbons on benthic macrofaunal community structure in Sydney Harbour, Nova Scotia. MSc thesis, Department of Oceanography, Dalhousie University, Halifax, NS

Stewart ARJ, Milligan TG, Law BA, Loring DH (2001) Disaggregated inorganic grain size and trace metal analyses of surficial sediments in Sydney Harbour, NS. Can Data Rep Fish Aquat Sci 1072

Stewart PL, Kendrick PA, Robinson TL, Lee K (2002) Softbottom bentic communities in Sydney Harbour, Nova Scotia. 1: 1999 Survey – Distribution, relation to contamination and conmparison to previous studies. Can Tech Rep Fish Aquat Sci 2424

Stewart PL, Kendrick PA, Levy HA, Robinson TL, Lee K (2002) Softbottom bentic communities in Sydney Harbour, Nova Scotia. 2: 2000 Survey – Distribution and relation to sediments and contamination. Can Tech Rep Fish Aquat Sci 2425

Tay KL, The SJ, Doe K, Lee K, Jackman P (2003) Histopathologic and histochemical biomarker responses in Baltic clams, *Macoma balthica*, to contaminated Sydney Harbour sediment, Nova Scotia, Canada. Environ Health Perspect 111:273-280

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SOURCES AND DISTRIBUTION OF METAL CONTAMINATION IN SURFICIAL SEDIMENTS OF SYDNEY HARBOUR, NOVA SCOTIA

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Geochemical studies in Sydney Harbour indicate that its sediments are contaminated to varying degrees with 'pollution' metals such as As, Cd, Hg and Pb. Results based on the analyses of 119 surface sediment samples show that above background concentrations of Ag, As, Bi, Cd, Cu, Hg, Mo, P, Pb, Sb, and Zn occur in the sandy muds and muds adjacent to the urban and industrial development on the east side of the South Arm and the Sydney River estuary. The distributions of these metals are more strongly controlled by the individual anthropogenic sources of the metals than by the natural depositional patterns. Flocculation and deposition of anthropogenic material in the immediate vicinity of the sources is of greater importance than the more general dispersal, flocculation and settling of fine grained material in the harbour. Organic matter, which is a significant component of many of these inputs, plays an important role in the sequestering and settling of the metals close to the sources. The distributions of Al, Ba, Co, Cr, Fe, Li, Ni, Sr, Ti and V, on the other hand, are controlled by the dispersal, flocculation, settling and resuspension of fine grained aluminosilicate-bearing sediments in response to natural depositional conditions.

Il ressort d'études de géochimie réalisées dans le port de Sydney que les sédiments du port sont contaminés à divers degrés par des métaux polluants comme As, Cd, Hg et Pb. Les résultats des analyses de 119 échantillons de sédiments superficiels dénotent la présence de concentrations de Ag, As, Bi, Cd, Cu, Hg, Mo, P, Pb, S et Zn supérieures aux teneurs naturelles dans les vases et les boues sableuses adjacentes aux aménagements urbains et industriels situés sur la rive est du bras sud et dans l'estuaire de la rivière Sydney. La répartition de ces métaux est déterminée par la source anthropique de chacun davantage que par les régimes naturels de sédimentation. La floculation et le dépôt de matières anthropiques dans les environs immédiats des sources revêtent plus d'importance que le processus général de dispersion, de floculation et de sédimentation des matières à grain fin dans le port. Les matières organiques, qui représentent une importante composante d'un bon nombre de ces apports, jouent un grand rôle dans la séquestration et la sédimentation des métaux à proximité des sources. Par ailleurs, la répartition de Al, Ba, Co, Cr, Fe, Li, Ni, Sr, Ti et V est régie par la dispersion, la floculation, la sédimentation et la remise en suspension des sédiments à grain fin contenant de l'aluminosilicate en fonction des conditions naturelles de sédimentation.

INTRODUCTION

In coastal areas adjacent to population centres and industrial activities, sediments are a major repository for metal contamination, and a potential

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source for subsequent remobilization of these metals. Sydney Harbour located on the northeast coast of Cape Breton Island in Nova Scotia, Canada is an example of a harbour subject to sedimentary metal contamination resulting from urbanization and industrial activities surrounding the harbour.

Sydney (with a population of 24,000 according to the 2001 census) is the second largest city in Nova Scotia and approximately 50,000 people live in the area surrounding Sydney Harbour. The main point-sources of waste to the harbour have historically been extensive shipping activity, domestic and industrial raw sewage which enters through numerous discharges, and the Sydney Steel Corporation (Sysco) steel foundry operations including coal-coking (terminated in the 1980s) and steel manufacture. The steel mill and coke oven effluent drained into Coke Oven Brook and the Sydney Tar Ponds. The Tar Ponds are an area at the mouth of the freshwater portion of Muggah Creek which is separated from the estuarine portion of Muggah Creek by a causeway. The Tar Ponds are highly enriched in polyaromatic hydrocarbons and metals and continue to release contaminated effluent to the estuarine portion of Muggah Creek (Stewart & White 2001). A major engineering project is now underway for the containment and/or removal of the contaminated materials from the Coke Ovens site, Coke Oven Brook, the Tar Ponds and Muggah Creek. PWGSC (2005) describes the extent of this project including requirements for environmental monitoring.

Sydney Harbour is a Y-shaped estuary comprising an outer harbour, the North West Arm (axial length 8.1 km, width 2.6 km) and the South Arm (axial length 10.7 km, width 2.2 km) which connects to Sydney River. The total surface area of the harbour is 52 km^2 with a volume of 5.17×10^8 m^3 and a maximum depth of 19 m (Gregory et al. 1993). The tides are semi-diurnal with amplitudes of 0.9 m, tidal volume of 4.79×10^7 m^3, and peak tidal current speeds of 0.05 m/s. Flushing time is on the order of 140 hours. Current meter observations show that the residual circulation is estuarine with net outflow in a very shallow surface layer and net inflow at greater depth (Petrie et al. 2001). Studies of metal and PAH contamination of Sydney Harbour sediments from the 1980s to early 1990s are summarized by Vandermeulen (1989) and Stewart and White (2001). These studies show highly elevated concentrations of Cd, Cu, Pb and Zn at a small number of stations in the estuarine part of Muggah Creek, and generally higher levels of these metals in the Sydney River estuary and the central part of the South Arm than in the rest of the harbour.

In our study, surficial sediment samples were collected from 119 sites throughout Sydney Harbour to establish the geochemical factors controlling the accumulation and dispersal of the metals in the harbour. This study is a component of an extensive assessment of contaminant distributions and biological effects in the harbour that was funded by the Toxic Substance Research Initiative (TSRI) of Health Canada (see Lee (2002) for summary of results of this project). The description of metal distributions in surficial sediments presented in this paper should provide a valuable reference point

for on-going monitoring and final assessment of the success of the recently initiated Tar Ponds clean-up.

METHODS

Surficial sediment samples were collected at 94 sites using a 0.1 m^2 Eckman grab, hand-deployed from a Boston Whaler, in October 1999. The top 1 cm of the grab was sub-sampled using a modified 10 ml plastic syringe. The sediment sub-samples were placed in 25 ml plastic Bitran bags to be analyzed for water content and grain size. A second 50 ml sub-sample, for trace metal analysis, was taken from the top 1cm of the sediment using a plastic spoon, placed in 125 ml plastic specimen containers, and stored at -15°C. All samples were returned to the laboratory for processing. A second set of 30 sediment samples was collected at the same time from the CCGS Navicula for trace metal analysis (no grain size measurements) using similar techniques, for a total of 124 samples.

Salinity and temperature profiles were obtained at or adjacent to 54 of the stations using a Seabird 25 CTD. The station locations are shown in Fig 1. Station and sample information for the Boston Whaler samples and a complete listing of grain size results are available (Stewart et al. 2001).

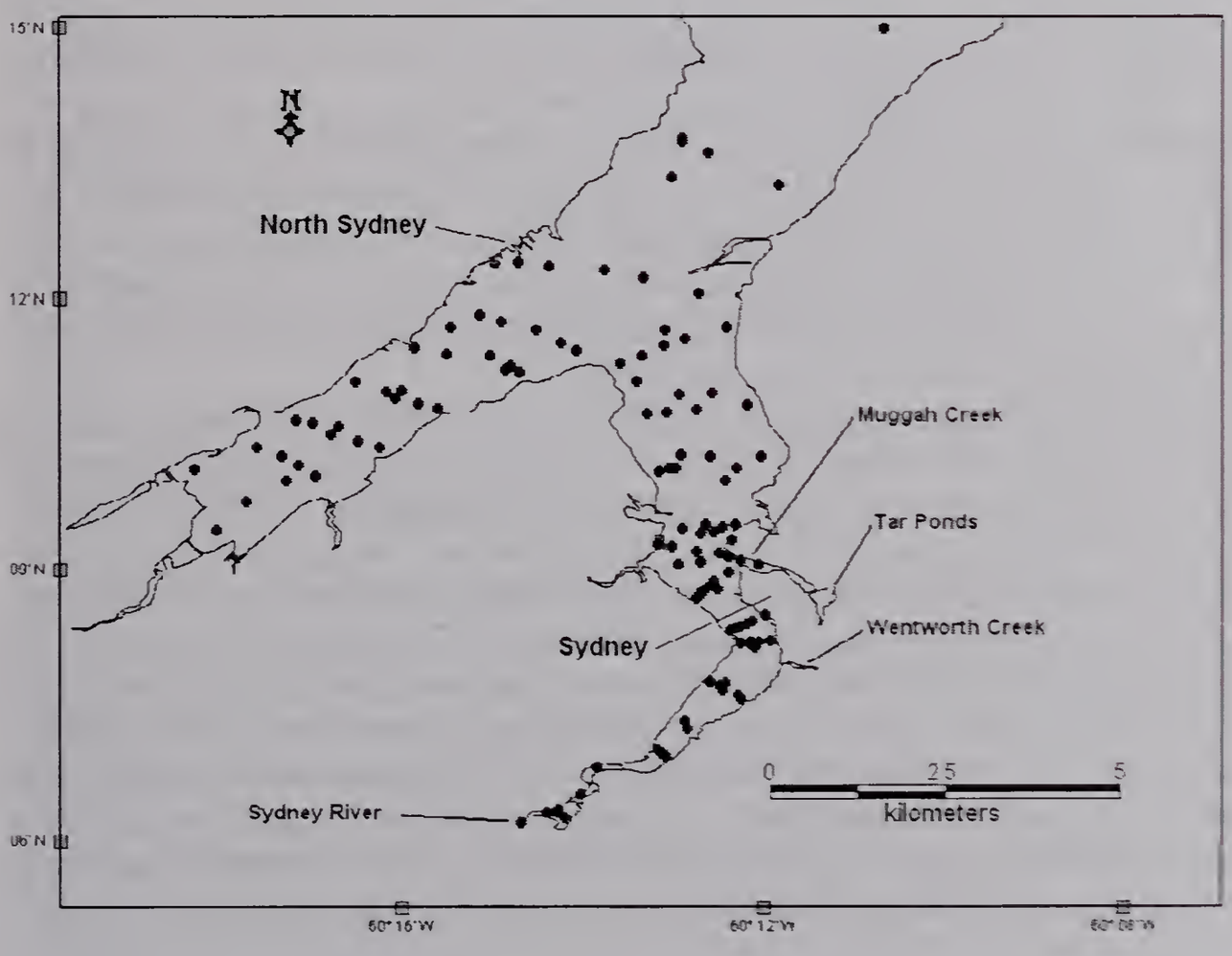

Fig 1 Map of harbour showing sampling locations and geographic locations mentioned in the text.

The disaggregated inorganic grain size (DIGS) of each of the Boston Whaler samples was determined by electro-particle sizing techniques described by Milligan and Kranck (1991). Sediment samples were placed in 20 ml Pyrex beakers, weighed wet, air-dried, and subsequently re-weighed. The samples were then digested in an excess of 35% H_2O_2, weighed again, re-suspended in 1% NaCl, and finally disaggregated with a sapphire tipped sonic probe. The DIGS distributions were determined using the Coulter Multisizer IIe over a size range from 0.87 to 500 μm. Percentage weight of the sediment was calculated using a specific gravity of 2.65 kg/m^3 to convert sediment volume to weight, which was then normalized to total sediment weight in the size range analyzed. Diameters are reported as the midpoint of the size class based on a 1/5 ϕ interval (i.e. the diameter doubles every 5 channels).

All sediment samples for metal analysis were dried at 58°C prior to homogenization with a mortar and pestle. Samples were analyzed by Chemex Labs (Toronto, Ont.) for Ag, Al, As, Ba, Bi, Ca, Cd, Co, Cr, Cu, Fe, Hg, Li, Mo, Mn, Ni, P, Sb, Sr, Ti, U and V, and Zn. Samples except for mercury were triple acid digested ($HF/HCl/HNO_3$) and analyzed by a combination of Inductively Coupled Plasma - Atomic Emission Spectroscopy (ICP-AES) and Inductively Coupled Plasma - Mass Spectrometry (ICP-MS). Mercury (Hg) was determined using sulphuric acid digestion and a cold vapour atomic absorption technique. NRCC-certified marine sediment reference materials (MESS-2, PACS-2) were included in the analysis to ensure quality control. Readily oxidizable organic carbon content was determined for 49 of the Boston Whaler samples (35 from the South Arm and 14 from the North West Arm and outer Harbour) by the Walkey-Black method adopted and modified by Jackson (1958). This method differentiates humus matter from extraneous sources of organic carbon such as graphite and coal. For the determination of total organic carbon, the Navicula samples were washed with dilute HCl at 60°C to remove carbonates, dried at 80°C and analysed with a LECO carbon analyser.

Lithium normalization procedures (Loring 1990, 1991) were used to compensate for the effect of grain-size and mineralogical variability on the metal distributions. Factor analyses were also used to establish the geochemical factors controlling the accumulation and dispersal of the metals. For this study, the principal factor (correlation) matrices were rotated to produce normal varimax orthogonal solutions. Since organic matter is also an important carrier of metals in coastal environments, the factor analysis and discussions of metal carriers and dispersal factors was based on the subset of samples from the South Arm (n=35), the North West Arm and outer harbour (n=14) for which the readily oxidizable organic matter data were available. Maps showing metal distributions were generated using Map Info Vertical Mapper using natural neighbour interpolation.

RESULTS

Sediment distribution and characteristics

The depositional history of the sediment can be determined through the analysis of the DIGS (Kranck et al. 1996a, b). The inorganic fraction of the sediment can be divided into the three components from which it was formed: material settled as flocs, material settled from suspension with no subsequent re-working (termed one-round), and material that has been re-worked, usually under high energy conditions, and has become well-sorted. The DIGS analysis from Sydney Harbour indicated mainly floc-deposited and single-grain sediment for most of the Harbour with well-sorted, high-energy sediments located at the mouth. The average percentages of the sediment, by weight, that were <64 μm and <5 μm are listed in Table 1 for the sediments from Sydney River and the six subdivisions of the harbour

Table 1 Grain size and organic carbon data for sediments from the seven harbour areas.

	< 5 μm (wt %)*	< 64 μm (wt %)*	Organic C (wt %)*	Organic C (wt %) +
River	33.0±9.5 (n=7)	90.3±10.0 (n=7)	9.29±0.94 (n=4)	
Estuary	37.7±11.9 (n=20)	91.1±21.0 (n=20)	6.97±2.62 (n=14)	8.05±1.06 (n=2)
Central South Arm	34.3±12.1 (n=15)	85.9±25.4 (n=15)	7.57±3.47 (n=13)	9.15±3.4 (n=10)
Outer South Arm	35.2±12.3 (n=9)	91.8±21.4 (n=9)	4.38±1.67 (n=2)	4.49±1.24 (n=7)
North West Arm	33.4±9.7 (n=21)	91.2±18.6 (n=21)	4.34±1.59 (n=10)	3.02±1.43 (n=6)
Central harbour	25.6±5.3 (n=15)	94.8±7.6 (n=15)	3.37±0.51 (n=5)	
Outer harbour	14.6±25.2 (n=4)	38.8±43.3 (n=4)		2.97±1.62 (n=4)

* samples from Boston Whaler survey.
\+ samples from Navicula survey.

identified in earlier studies (Stewart & White 2001). The <64 μm represents the silt + clay size fraction of the sediments that has been used to correlate trace metal concentration with fine sediment concentrations (Loring et al. 1998). The <5 μm fraction represents the very fine particulate fraction of the sediment that is associated with floc deposition. Sediments that had >90% silt + clay (<64 μm) content predominated in all areas except the outer harbour with the fraction of very fine-grained (<5 μm) material decreasing from 30-40% in the South and North West Arms to 25% in the central harbour and 15% in the outer harbour. Carbon content of the sediments decreased from 7-9% in the South Arm to approximately 3% in the central and outer harbour.

Estimations of the critical erosion shear stresses, based on DIGS data, were made using the expression of Wiberg and Smith (1987). Areas of low shear stress corresponded to regions dominated by floc deposition. The distribution of critical erosion shear stress indicated that Sydney Harbour is dominated by fine sediment deposited as flocs. This is important because trace metals and other contaminants are primarily associated with fine particulate matter in suspension (Muller 1996). Previous studies have shown that dredging operations can increase particle flux (Kranck & Milligan 1989). Dredging in depositional areas such as Sydney Harbour would release pore water and easily solubilzed metals to the water column but also has the potential to enhance the flux of trace metals to the sediment through increased flocculation.

Abundance and distribution of trace metals

Table 2 summarizes the average metal concentrations and standard deviations (SDs) for surficial sediments (0-1 cm) in Sydney River and the six subdivisions of the harbour identified in earlier studies (Stewart & White 2001). The results were similar to those of the earlier studies summarized in Stewart and White for the few metals (Cd, Cu, Hg, Pb and Zn) for which comparisons could be made, except for Hg where the maximum values seen in the estuary and central South Arm were clearly lower than those reported earlier.

Table 3 compares the mean concentrations of metals in Sydney Harbour and its two major arms with those found in sediments from Country, Halifax, Lunenburg and Shelburne harbours on mainland Nova Scotia. The overall average concentrations of As and Co in Sydney Harbour were slightly higher than those of the other harbours. Cadmium concentrations were higher than those of Country and Shelburne Harbours, but lower than those from Lunenburg and Halifax harbours. Chromium values were similar to Country Harbour, lower than Lunenburg and Halifax harbours, but higher than those from Shelburne Harbour. Mercury concentrations were higher than those from Country and Shelburne harbours, but lower than those found in the other harbours listed in Table 3. Nickel values were lower than those found in Lunenburg and Shelburne Harbours. Lead concentrations were higher than those found in all Harbours except Halifax Harbour. Antimony and V values were higher than those found in Country, Lunenburg and Shelburne harbours; and Zn values were higher than those found in Country, Lunenburg and Shelburne harbours, but lower than those found in Halifax Harbour. The concentrations of Ag, As, Bi, Cd, Cu, Hg, Mo, Pb, Sb and Zn were significantly higher (student t test, $p<0.05$) in the more developed and industrialized South Arm of Sydney Harbour than in the North West Arm and outer harbour. The concentrations of metals such as Cd, Cu, Pb and Zn were similar to those found in other developed harbours such as Halifax and Lunenburg. In the North West Arm and outer Sydney Harbour, concentrations of the metals were more like those in the less developed Country and Shelburne harbours.

Table 2 Metal distributions in seven harbour areas (mean ± standard deviation, mg/kg except wt % as indicated)

	River n=7	Estuary n=22	Cent. S. Arm n=25	Outer S. Arm n=15	N. W. Arm n=27	Central Hrbr n=16	Outer Hrbr n=6
Ag	0.81±0.26	1.50±0.74	1.64±1.56	0.86±0.26	0.67±0.25	0.63±0.13	0.21±0.09
Al (%)	5.04±0.71	5.90±1.19	6.13±1.54	7.08±0.81	7.21±1.16	7.08±0.90	3.69±0.98
As	16.4±6.5	20.6±8.0	26.2±11.2	21.1±8.1	15.7±5.3	14.5±2.9	14.4±2.6
Ba	266±11	336±70	361±88	424±66	437±57	459±42	362±48
Bi	0.50±0.19	0.84±0.39	0.92±0.59	0.66±0.34	0.39±0.14	0.35±0.12	0.11±0.04
Ca (%)	1.90±1.67	0.84±0.36	0.79±0.56	0.65±0.34	0.71±0.22	0.68±0.15	0.59±0.15
Cd	0.89±0.31	0.86±0.38	1.25±0.72	0.63±0.41	0.45±0.13	0.26±0.08	0.06±0.06
Co	10.3±1.6	12.4±2.9	12.5±2.6	14.0±0.9	13.5±2.1	14.1±1.3	7.8±1.9
Cr	44.7±9.6	59.0±13.7	71.3±18.7	72.5±7.3	64.4±14.0	65.1±9.6	28.6±10.8
Cu	39.4±14.9	69.5±30.2	81.3±67.4	42.8±15.1	34.0±11.7	30.9±7.0	10.4±4.9
Fe (%)	3.08±0.61	3.80±0.90	4.52±1.18	4.55±0.83	3.76±0.71	3.87±0.56	2.19±0.42
Hg	0.11±0.07	0.18±0.11	0.33±0.34	0.10±0.07	0.04±0.02	0.10±0.28	0.02±0.01
K (%)	1.58±0.21	1.74±0.32	1.78±0.45	1.97±0.23	2.05±0.30	1.94±0.28	1.07±0.14
Li	43.9±9.2	51.3±11.5	51.3±12.2	55.6±7.4	57.7±11.9	53.9±6.7	25.7±9.7
Mg (%)	0.97±0.23	1.15±0.24	1.18±0.23	1.10±0.14	1.17±0.20	1.00±0.17	0.45±0.15
Mn	396±74	410±114	417±78	449±82	457±126	584±71	652±89
Mo	4.1±1.6	7.0±3.1	8.3±3.6	2.8±2.9	4.4±1.7	2.9±1.4	1.0±0.8
Ni	20.8±3.8	27.9±7.4	30.2±6.7	32.6±2.5	29.7±5.9	30.3±3.6	13.2±5.1

Table 2 Continued

	River n=7	Estuary n=22	Cent. S. Arm n=25	Outer S. Arm n=15	N. W. Arm n=27	Central Hrbr n=16	Outer Hrbr n=6
P (%)	0.10±0.03	0.09±0.02	0.11±0.06	0.10±0.03	0.09±0.02	0.08±0.02	0.05±0.01
Pb	85±27	161±78	201±124	110±52	71±31	50±19	18±5
Sb	0.91±0.16	1.66±0.70	1.94±0.87	1.52±0.51	1.07±0.34	1.27±0.72	0.60±0.24
Sr	145±36	122±25	159±160	129±12	133±15	136±16	100±26
Ti (%)	0.22±0.02	0.24±0.05	0.24±0.06	0.28±0.03	0.30±0.05	0.31±0.03	0.17±0.05
Tl	0.60±0.07	0.70±0.16	0.80±0.22	0.71±0.12	0.71±0.11	0.61±0.08	0.31±0.07
U	2.97±0.60	3.82±0.96	3.84±1.06	3.77±0.63	3.59±0.73	3.20±0.48	1.72±0.61
V	79±11	104±24	114±28	128±18	116±22	110±18	50±14
Zn	173±41	237±91	316±156	201±88	139±36	115±32	50±16

Table 3 Comparison of metal concentrations (mg/kg) in Sydney Harbour with those in other Nova Scotia inlets

	n	As	Cd	Co	Cr	Cu	Hg	Li	Mn	Mo	Ni	Pb	Sb	U	V	Zn
Sydney Harbour	118	19.6	0.71	13	63	51	0.15	52	459	5.6	29	118	1.4	3.6	109	200
Sydney – Outer harbour & N W Arm	42	15.9	0.37	13	60	31	0.07	53	506	3.7	28	61	1.0	3.3	106	125
Sydney – South Arm	76	21.6	0.90	13	65	62	0.20	52	433	6.7	29	150	1.6	3.7	111	242
Country Harbour*	28	14.7	0.41	8	59	18	0.05	49	486	3	21	25	0.51	2	67	70
Halifax Harbour^	250		0.81		85	91	0.92	54	663		142	160				226
Lunenburg Harbour*	14	14.1	1.31	8	83	58	0.22	55	612	9	27	42	0.7	3.6	81	159
Shelburne Harbour*	23	13.7	0.48	7	28	16	0.06	33	625	3	45	29	0.53	2.3	43	45

* Loring et al. (1996) ^ Buckley and Winters (1992)

Most (71 to 80%) of the samples from the South Arm (Sydney River, estuary and central and outer South Arm) had concentrations of Ag, Bi, Cd, Cu, Pb and Zn that were above background concentrations. For As, Hg, Mo and Sb the percentages of samples greater than background were somewhat less (53-64%) whilst for Co, Cr, Ni and V, they were <30%. Background metal-Li relationships for Sydney Harbour were established using the samples from the North West Arm and outer harbour (Loring 1990, 1991). Two samples that were obviously contaminated with a number of metals were excluded from this analysis, all the rest of the North West Arm and outer Harbour samples were assumed to represent background conditions. The relationships between metals and Li are illustrated in Fig 2 with one example from each of the three groups of metals identified above. Comparison of the concentrations in this part of Sydney Harbour to concentrations (and metal-Li relationships) in other relatively pristine harbours such as Country Harbour, St. Mary's Estuary, Petpeswick Inlet and Pubnico Harbour suggested that this was not an unreasonable assumption except in the case of Pb, where concentrations normalized for grain size were approximately twice those in the reference harbours. For As and Hg, good relationships to Li could not be established for the North West Arm/outer harbour subset, so background concentrations of 20 mg/kg for As and 0.10 mg/kg for Hg were estimated based on more general comparisons to the literature for pristine areas (Loring et al. 1996).

The highest concentrations of Ag, As, Bi, Cd, Cu, Hg, Mo, P, Pb, Sb, and Zn occurred in the sandy muds and muds adjacent to the urban and industrial development on the east side of the central South Arm and into the Sydney River estuary. Fig 3 shows that the highest concentrations of Ag occurred in an extensive area of the eastern shore just south of Wentworth Creek and at a more intense 'hot spot' at the mouth of Muggah Creek. The Cu distribution was very similar. High concentrations of Pb (Fig 4) occurred along the axis and eastern side of the South Arm with the highest concentrations off the mouth of Muggah Creek and off the central part of the City of Sydney. The Zn distribution was very similar. High average Hg levels (and large standard deviations) in the central South Arm and the central harbour (Table 2) were the result of three samples (two in the central South Arm at the mouth of Muggah Creek and one off North Sydney) with very high concentrations of Hg (>1 mg/kg). Otherwise Hg concentrations were not particularly high. A second group of metals that included Al, Ba, Co, Cr, Fe, K, Li, Ni, Th, Ti and V had their highest concentrations in the outer South Arm, the North West Arm and the central harbour. The distributions of these metals, as illustrated by the distribution of Ni (Fig 5), more closely followed the pattern shown for shear stress and the deposition of fine sediments.

Surface sediment metal carriers and dispersal factors

In general, the trace metals have been introduced into these sediments as constituents of, or in association with, solid inorganic and organic particles supplied from natural and anthropogenic sources or precipitates

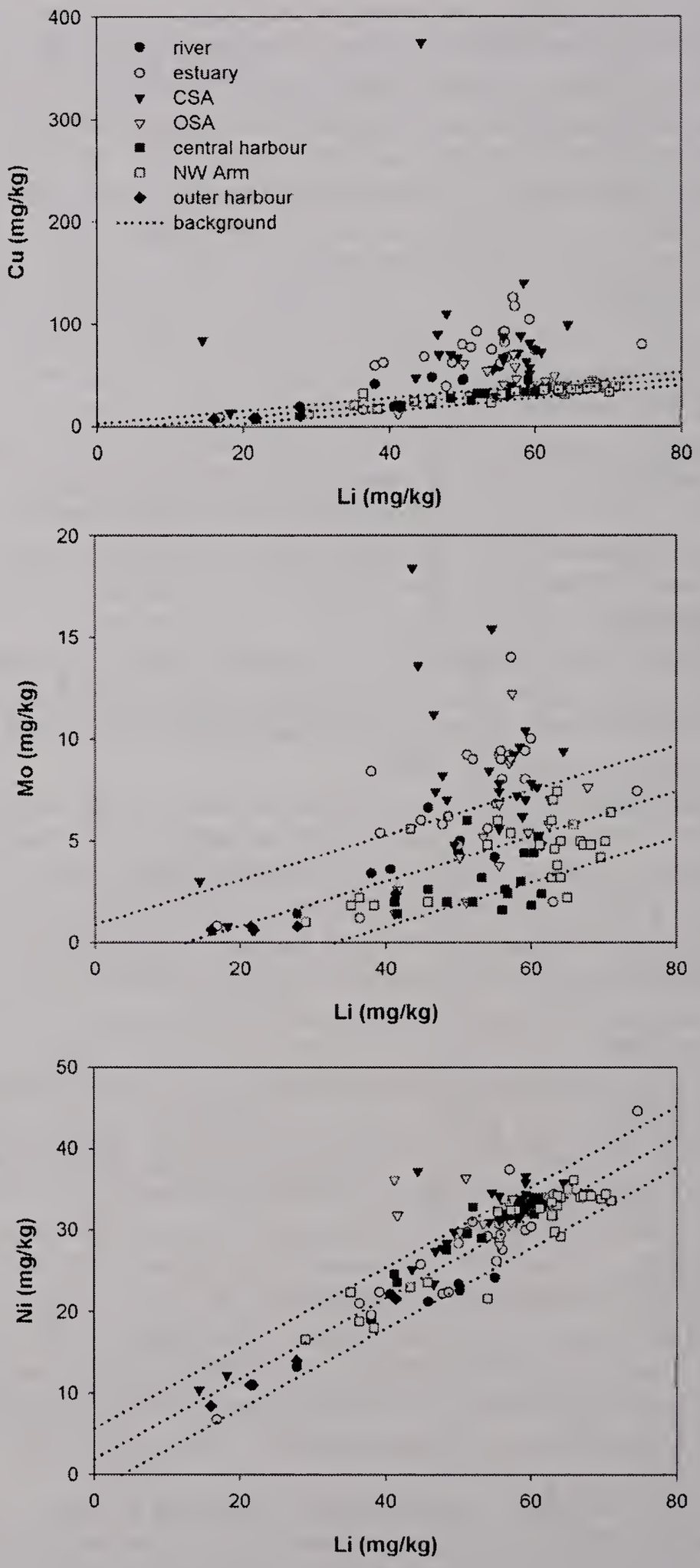

Fig 2 Cu, Mo and Ni vs. Li plots. The dotted lines represent the Metal:Li regression line and 95% confidence band for data from the North West Arm and outer harbour.

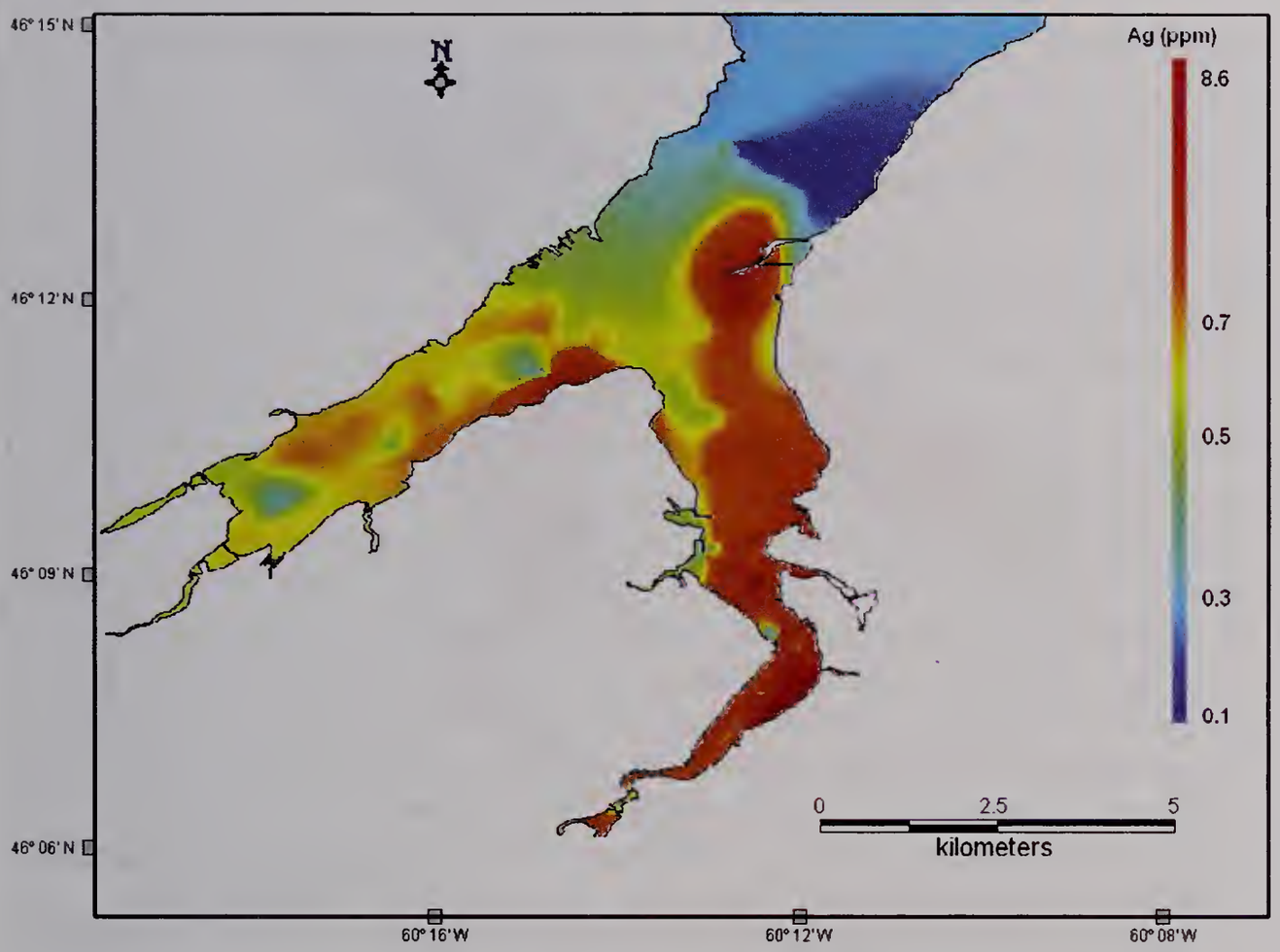

Fig 3 Ag distribution (mg/kg) in surficial sediments of Sydney Harbour.

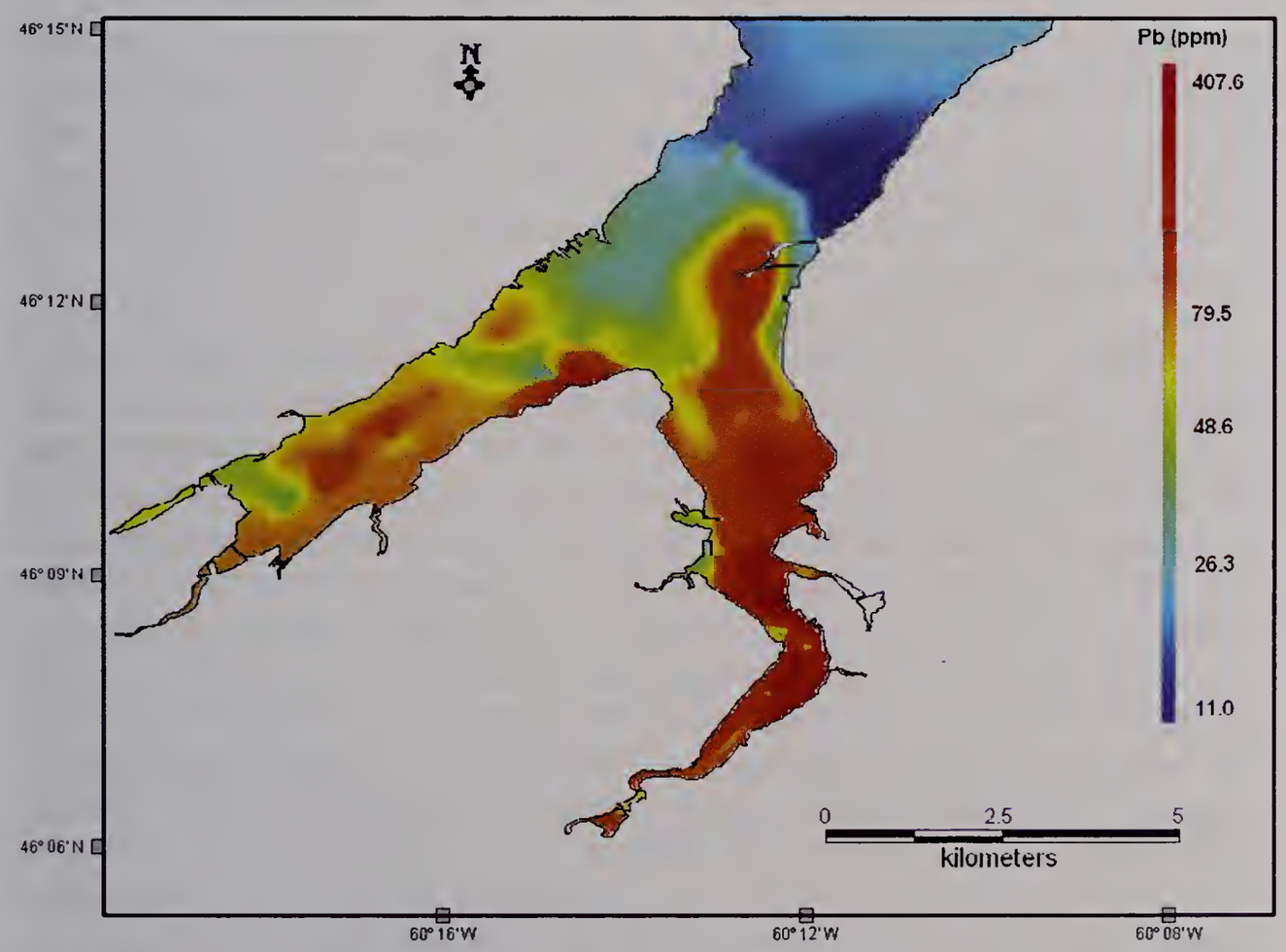

Fig 4 Pb distribution (mg/kg) in surficial sediments of Sydney Harbour.

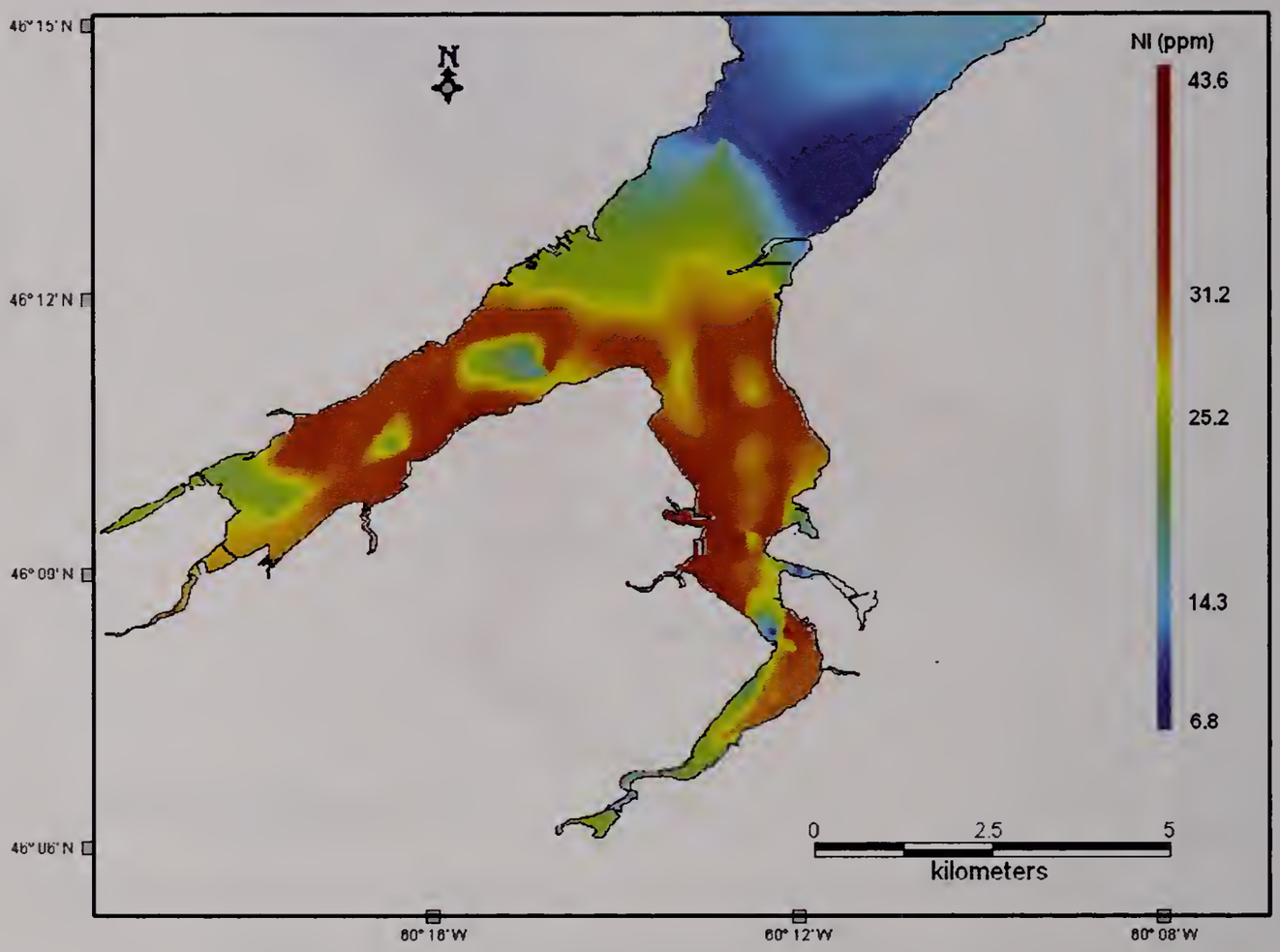

Fig 5 Ni distribution (mg/kg) in surficial sediments of Sydney Harbour.

from solution. Provenance, mineralogy, grain-size, depositional conditions, and anthropogenic inputs therefore determine the trace metal chemical composition of the sediments. Since organic matter is also an important carrier of metals in coastal environments, the discussions on metal carriers and dispersal factors are based on those samples for which organic matter contents are available.

Strong ($p \leq 0.01$) positive correlations of Al, Ba, Co, Cr, Li, Mn, Ni, Sr, Ti and V, with the <64 µm size fraction suggested that carriers of these metals were predominantly enriched in the fine-grained sediments of Sydney River and the South Arm as well as for Al, Cr, Li, Ni, Sr, Ti, and U in the North West Arm and outer harbour sediments. The strong positive covariances ($p \leq 0.01$) of the metal concentrations with Al and Li concentrations showed that Li and/or Al normalized for most of the granular and mineralogical variability of Ba, Cr, Co, Fe, Ni, Sr, Ti, U, and V (see Fig 2 for relationship between Ni and Li). The data reflect the association with and/or inclusion of these metals in the lattices of fine-grained aluminosilicate minerals such as micas, ferromagnesium silicates (pyroxenes, hornblendes) and clay minerals (illite, smectite and chlorite) that most likely constituted the bulk of the fine-grained sedimentary material. The strong covariances of Ag, Bi, Cd, Cu, Hg, Pb and Zn with the organic matter and phosphorus in the Sydney River and South Arm sediments suggested that these metals were associated with the presence of natural and anthrophogenic organic matter including that

derived from sewage outfalls. Arsenic covaried ($p \leq 0.01$) with Bi, Fe, Pb, Sb, and Zn in these sediments. In the North West Arm and outer harbour sediments, Cd, Mo, and U were also closely correlated ($p \leq 0.01$) with the organic component and with phosphorus. Iron covaried ($p \leq 0.01$) with Ag, As, Bi, Cu, Hg, Pb and Zn.

Factor analyses of the two data sets established the most likely geochemical factors that control the accumulation and dispersal of metals in the Sydney River and South Arm sediments as well as those factors for the North West Arm and outer Harbour sediments.

The varimax matrix (Table 4) for Sydney River and South Arm shows that five factors account for 87% of the total problem variance. Factor 1 accounts for 32% of the total problem variance. This factor has significant positive loadings on Al, Ba, Co, Cr, Li, Ni, Sr, Ti, V, and material <64 μm. This may be identified as the sedimentation factor. It represents the accumulation of fine-grained aluminosilicates with their accompanying lattice trace metals in response to the present depositional conditions. Factor 2 accounts for 32% of the total variance and has significant loadings on organic matter and phosphorus as well as many of the chalcophile metals. It indicates that organic matter controls the abundance and distribution of Ag, Bi, Cd, Cu, Hg, P, Pb, Sb and Zn in the sediments. The inclusion of phosphorus in this factor suggests that sewage is the main source of the organic matter. Factor 3 accounts for 8.2% of the total variance. The significant loadings on Mo and U alone suggest that the small amounts of these metals behave independently. Factor 4 accounts for 8.9% of the total variance. Significant loadings of As, Pb, and Fe on this factor suggest the presence of independent As and Pb bearing Fe minerals or possibly anthropogenic Pb and As-Fe particles released from the of the Sysco coking operations control the abundance and distribution of As and Pb in the sediments. Factor 5 accounts for 6.4% of the total variance. Significant positive loadings on Ca in this factor alone suggest that the abundance and distribution of Ca in these sediments is derived from shell fragments.

The varimax matrix for the North West Arm and outer Harbour sediments shows that three factors account for 89% of the total problem variance. Factor 1 accounts for 39% of the total variance and has significant loadings on Al, Co, Cr, Fe, Li, Ni, Sr, Ti, U and V, as well as on material <64 μm. This is the sedimentation factor and represents the accumulation in response to present depositional conditions of fine-grained aluminosilicates with their accompanying lattice-bound trace metals. Factor 2 accounts for 35% of the total problem variance with significant loadings on Ag, As, Bi, Cd, Cu, Hg, Pb, Sb and Zn. This factor can be identified as the anthropogenic or contamination factor. It represents the enrichment of these metals above background levels by anthropogenic sources such as sewage discharges and past industrial activity. It is possible that these metals reside in the sediments as authigenic sulphides.

Factor 3 (15% of the total variance) has significant negative loadings on organic matter, Cd and Mo, and positive loadings on Ca and Mn. This fac-

Table 4 Varimax matrices for metals from Sydney River and South Arm, and North West Arm and outer harbour showing component loadings for each factor.

	Sydney River and South Arm					North West Arm and outer harbour		
Factor	**1**	**2**	**3**	**4**	**5**	**1**	**2**	**3**
OM		0.73						-0.79
<64µm	0.75					0.70		
Ag		0.97					0.94	
Al	0.96					0.99		
As				-0.82			0.76	
Ba	0.89							
Bi		0.89					0.93	
Ca					0.88			0.72
Cd		0.91					0.63	-0.71
Co	0.91					0.97		
Cr	0.75					0.95		
Cu		0.97					0.95	
Fe				-0.63		0.86		
Hg		0.71					0.98	
Li	0.81					0.94		
Mn								0.70
Mo			-0.81					-0.77
Ni	0.89					0.97		
P		0.91						
Pb		0.59		-0.6			0.96	
Sb		0.69					0.94	
Sr	0.63					0.95		
Ti	0.94					0.91		
U			-0.82			0.67		
V	0.84					0.89		
Zn		0.93					0.91	
%	31.8	31.7	8.2	8.9	6.4	39.4	35.0	15.0

OM = organic matter; <64 µm = <64 µm size fraction;
% = % of total problem variance explained by each factor

tor most likely reflects the dilution of the Cd and Mo bearing organic matter by carbonate debris in the harbour sediments.

DISCUSSION

It is clear from an inspection of Table 2 and the factor analysis that the distributions of the majority of the metals can be described by one of two patterns. The distributions for the first group (those in factor 1 of the factor analyses) were controlled by the dispersal, flocculation, settling and resuspension of fine grained sediments. The estimation of critical erosional shear stress from the DIGS data showed that the areas of low shear stress where floc deposition occurs correspond quite closely to areas with high concentrations of these more detrital metals (as illustrated by the distribution of Ni shown in Fig 5). The correlation coefficients for the linear regressions

of these metals with shear stress varied from r = 0.4 to r = 0.6, all of which are significant at $P<0.01$.

The second group of metals (those in factor 2 of the factor analysis) contained the potentially toxic metals such as As, Cd, Hg and Pb that are generally the focus of environmental concerns. For these elements, the distributions were more controlled by the individual anthropogenic sources of the metals than by the depositional patterns in the harbour. For the input from these sources, flocculation and deposition of the anthropogenic material in the immediate vicinity of the sources was more important than the more general dispersal, flocculation and settling of fine grained material in the harbour. Organic matter, which was a significant component of inputs such as sewage discharges, played an important role in the sequestering and settling of the metals close to the sources. Surprisingly, there was no evidence to indicate that runoff and/or discharge from the Tar Ponds made a dominant contribution to the concentration of potentially toxic metals such as As or Cd in the sediments of South Arm.

There was not a single common source for all these anthropogenic metal inputs. The distribution seen for Ag (Fig 3) and Cu (r = 0.955 for the correlation between Ag and Cu) with highest concentrations in the area off and to the south of Wentworth Creek and off the mouth of Muggah Creek were entirely consistent with the fact that the largest sewage and storm water discharges to Sydney Harbour were into these two areas. The 'hot spot' near Wentworth Creek should be a more or less purely sewage signal as there were no other major sources in this area, but the one off Muggah Creek reflected sewage inputs, inputs from the Sydney Tar Ponds and/or other industrial inputs from the central core of Sydney or the International Piers area just to the north of Muggah Creek. The distributions seen for Pb (Fig 4) and Zn (r = 0.929 for the correlation between Pb and Zn) with the highest concentrations off and to the south of Muggah Creek reflected the relatively greater importance of these additional sources for Pb and Zn compared to Ag and Cu. Observations (summarized in Stewart and White (2001)) of very high concentrations of As, Cd, Cr, Cu, Pb, Hg and Zn in sediments from the central part of Muggah Creek indicated that the Tar Ponds were an important source of the metals in Muggah Creek, but even within Muggah Creek, differences in distributions of PAHs and metals suggested that the Tar Ponds were not the only source for metals.

Ernst et al. (1999) observed that concentrations of a number of metals, most notably Cu, Pb and Zn, were higher in sediments to the south of Muggah Creek than to the north. This is consistent with our observations as illustrated by the Pb distribution (Fig 3). They concluded that these observations indicated that "Muggah Creek was not the only, and may not even be the most important, source of metals in Sydney Harbour". Our data confirmed the importance of other sources, most notably the contribution from the sewage sources in the Wentworth Creek area for Ag and Cu. We should point out, however, that the estuarine circulation pattern in the harbour will transport particulate matter and metals introduced into

the deeper waters, or particulate matter and associated metals that settle out of the surface layer, in a net inward (southward) direction. Because the net transport of the deeper layer of this estuarine circulation is inward, contaminants introduced into Muggah Creek could be transported to the south and contribute to the elevated levels seen in the sediments in the central South Arm south of Muggah Creek.

CONCLUSIONS

Sydney Harbour provides an excellent example of sedimentary metal contamination resulting from adjacent urban and industrial activities. Sedimentary geochemical and particle dynamic studies of the Y-shaped Sydney Harbour indicated that its surficial sediments were contaminated to varying degrees with Ag, As, Bi, Cd, Cu, Hg, Mo, P, Pb, Sb and Zn. The concentrations of these metals were significantly higher (student t test, $p<0.05$) in the more developed and industrialized South Arm than in the North West Arm and outer Sydney Harbour with elevated concentrations in the sandy muds and muds adjacent to the urban and industrial development on the east side of the South Arm and the Sydney River estuary. The concentrations of metals such as Cd, Cu, Pb and Zn were similar to those found in other developed harbours in Nova Scotia such as Halifax and Lunenburg. In the North West Arm and outer Sydney Harbour concentrations of the metals were more like those in the less developed Country and Shelburne harbours.

The distributions of most of the metals can be described by one of two patterns viz. natural and anthropogenic. The distributions of Al, Ba, Co, Cr, Fe, Li, Ni, Sr, Ti and V were controlled by the dispersal, flocculation, settling and resuspension of fine-grained aluminosilicate bearing sediments in response to the natural depositional conditions. The distributions of the potentially toxic metals, such as As, Cd, Hg and Pb, that are generally the focus for environmental concerns, were more controlled by the individual anthropogenic sources of the metals than by the depositional patterns in the harbour. For the inputs from these sources, flocculation and deposition of the anthropogenic material in the immediate vicinity of the sources was more important than the more general dispersal, flocculation and settling of fine-grained material in the harbour. Organic matter, which was a significant component of many of these inputs, played an important role in the sequestering and settling of the metals such as Ag and Hg close to their sources. Sewage and storm water runoff appeared to be the most important source of metallic contaminants to the surficial sediments but other sources, including runoff from the Tar Ponds, contributed to the observed distributions. There is also some suggestion from the data that deposition of Pb and As-rich particles derived from coking activity could have contributed to levels of these metals in the North West Arm and the outer harbour.

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REFERENCES

Buckley DE, Winters GV (1992) Geochemical characteristics of contaminated surficial sediments in Halifax Harbour: impact of waste discharge. Can J Earth Sci 29:2617-2639

Ernst B, Pitcher D, Matthews S, Julien G (1999) Concentrations and distribution of polycyclic aromatic hydrocarbons (PAHs), PCBs and metals in sediments, mussels (*Mytilus edulis* and *Modiolus modiolus*) and lobsters (*Homarus americanus*) from Sydney Harbour, Nova Scotia. Environment Canada Report EPS-5-AR-99-7

Gregory D, Petrie B, Jordan F, Langille P (1993) Oceanographic, geographic, and hydrological parameters of Scotia-Fundy and southern Gulf of St. Lawrence inlets. Can Tech Rep Hydrogr Ocean Sci 143

Jackson ML (1958) Soil chemical analysis. Prentice Hall, New York, p 219-221

Kranck K, Milligan TG (1989) Effects of a major dredging program on the sedimentary environment of Miramichi Bay, New Brunswick. Can Tech Rep Hydrogr Ocean Sci 112

Kranck K, Smith PC, Milligan TG (1996a) Grain-size characteristics of fine-grained unflocculated sediments I: 'one-round' distributions. Sedimentology 43:589-596

Kranck K, Smith PC, Milligan TG (1996b) Grain-size characteristics of fine-grained unflocculated sediments II: 'multi-round' distributions. Sedimentology 43:597-606

Lee K (2002) Environmental effects and remediation of contaminants in Sydney Harbour, Nova Scotia. Final report to Health Canada for Toxic Substances Research Initiative (TSRI) Project #93

Loring DH (1990) Lithium - a new approach for the granulometric normalization of trace metal data. Mar Chem 29:156-168

Loring DH (1991) Normalization of heavy-metal data from estuarine and coastal sediments. ICES J Mar Sci 48:101-115

Loring DH, Rantala RTT, Milligan TG (1996) Metallic contaminants in the sediments of coastal embayments of Nova Scotia. Can Tech Rep Fish Aquat Sci 2111

Loring DH, Milligan TG, Willis DE, Saunders KS (1998) Metallic and organic contaminants in sediments of the St. Croix Estuary and Passamaquoddy Bay. Can Tech Rep Fish Aquat Sci 2245

Milligan TG, Kranck K (1991) Electro-resistance particle size analysers. In: Syvitski JP (ed) Theory methods and applications of particle size analysis. Cambridge University Press, New York, p 109-118

Muller FLL (1996) Interactions of copper, lead and cadmium with the dissolved, colloidal and particulate components of estuarine and coastal waters. Mar Chem 52:245-268

Petrie B, Bugden G, Tedford T, Geshelin Y, Hannah C (2001) Review of the physical oceanography of Sydney Harbour. Can Tech Rev Hydrog Ocean Sci 215

PWGSC (Public Works and Government Services Canada) (2005) Remediation of Sydney Tar Ponds and Coke Oven sites – Draft scoping document

Stewart PL, White L (2001) A review of contaminants on the Scotian Shelf and in adjacent coastal waters: 1970-1995. Can Tech Rep Fish Aquat Sci 2351

Stewart ARJ, Milligan TG, Law BA, Loring DH (2001) Disaggregated inorganic grain size and trace metal analyses of surficial sediments in Sydney Harbour, N.S. 1999. Can Data Rep Fish Aquat Sci #1072

Vandermeulen JH (1989) PAH and heavy metal pollution of the Sydney estuary: summary and review of studies to 1987. Can Tech Rep Hydrogr Ocean Sci 108

Wiberg PL, Smith JD (1987) Calculations of the critical shear stress for motion of uniform and heterogeneous sediments. Water Resour Res 90:1471-1480

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HEAVY METAL DISTRIBUTIONS IN THE WATERS OF SYDNEY HARBOUR, NOVA SCOTIA

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Four surveys of total Hg and dissolved Cd, Cu, Fe, Mn, Ni, Pb and Zn concentrations in Sydney Harbour waters were conducted between 1999 and 2001. Suspended particulate matter samples were analysed for Cd, Cu, Fe, Mn, Ni, Pb, Zn and 22 other metals. The measurements were made to establish environmental context for toxicological studies, provide ground-truthing data for water quality modelling, and investigate estuarine geochemistry of heavy metals in a harbour subject to significant anthropogenic input. Despite the long history of metal contamination in Sydney Harbour, metal concentrations are almost all below water quality guidelines for estuarine or marine waters. The distributions of total Hg and dissolved Cu, Fe and Mn show that freshwater inputs are important contributors of these metals to the harbour. For Cu, Fe and Mn, additional inputs to the central part of South Arm are evident from the metal vs. salinity relationships. Particulate Cd, Cr, Cu, Pb, Mn, Ag and Zn distributions also show evidence of inputs in the central part of the harbour. Sewage appears to be the major, but not sole, source for these metals.

Quatre études des concentrations d'Hg total et de Cd, Cu, Fe, Mn, Ni, Pb et Zn dissous dans les eaux du port de Sydney ont été effectuées entre 1999 et 2001. On a analysé les échantillons des matières particules en suspension pour y déceler la présence éventuelle de Cd, Cu, Fe, Mn, Ni, Pb, Zn et 22 autres métaux. Les mesures obtenues visaient à établir le contexte environnemental des observations toxicologiques, à fournir des données de vérification pour la modélisation sur la qualité de l'eau et à étudier la géochimie estuarienne des métaux lourds dans un port soumis à apport anthropique important. Malgré les longs antécédents de contamination par les métaux dans le port de Sydney, les teneurs en métaux sont presque toutes inférieures aux concentrations indiquées dans les recommandations sur la qualité des eaux estuariennes ou marines. Il ressort de la répartition des concentrations d'Hg total et de Cu, Fe et Mn dissous que les apports en eau douce comptent pour beaucoup dans la présence de ces métaux au sein du port. Pour ce qui est des concentrations de Cu, Fe et Mn, la relation entre les métaux et la salinité met en évidence des apports supplémentaires dans la partie centrale du bras sud. La répartition des particules de Cd, Cr, Cu, Pb, Mn, Ag et Zn reflète aussi des apports dans la partie centrale du port. Les eaux usées semblent être la principale, mais non l'unique, source de ces métaux.

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INTRODUCTION

Wastes discharged from the Sydney Steel Plant and associated coke ovens to the Sydney Tar Ponds from the 1890s until the 1980s included very high concentrations of various hydrocarbon components and a number of heavy metals including Cu, Pb, Hg and Zn. Runoff and leachate from the Tar Ponds enters Sydney Harbour via Muggah Creek, a small tidal arm of the harbour. Numerous other discharges, including ~20,000 m^3/day of storm water and domestic and industrial sewage, enter the harbour from various locations including ~8,000 m^3/day into Muggah Creek (CBCL 1999). Contamination of harbour sediments and biota from the combination of these sources was initially assessed in the early 1980s (Matheson et al. 1983) and has been reassessed several times since, most recently by Ernst et al. (1999) and Stewart and White (2001). High levels of polyaromatic hydrocarbons (PAHs) and heavy metals were found in both sediments and biota. PAH contamination of lobster (Sirota et al 1984) resulted in an on-going closure of the commercial lobster fishery in the South Arm of Sydney Harbour commencing in 1982.

We measured water column concentrations of suspended particulate matter, nutrients, and dissolved and particulate heavy metals in Sydney Harbour on four occasions between October 1999 and May 2001 as part of an extensive reassessment of environmental contamination and biological effects in Sydney Harbour. This study is the most comprehensive assessment of chemical contamination of the water column to date. Previous assessments had focussed almost entirely on contamination of sediments and biota. Our study had three main objectives: to establish the contaminant reference levels for toxicological studies that were being made as part of an overall environmental assessment; to provide ground-truthing data for water quality modelling that was also being done as part of the assessment; and to investigate estuarine geochemistry of heavy metals in a harbour subject to significant anthropogenic chemical inputs. The results provide a timely assessment of environmental conditions prior to the commencement of a major Tar Ponds clean-up (PWGSC 2005).

METHODS

Water samples were collected from one of two small Canadian Coast Guard ships. In October 1999, October 2000 and May 2001 the samples were collected from the CCGS *Navicula* and in July 2000, from the CCGS *Earl Grey*. They were collected with 5 litre General Oceanics lever action Niskin bottles (Teflon-coated PVC) hung on a stainless steel hydrowire and tripped with Teflon messengers. Water samples were collected at surface and mid-depth from 9 to 16 stations on the surveys (Fig 1). Sampling for each of the surveys was spread over 1-3 days and not aligned with the state of the tide or other environmental factors. Conductivity and temperature were recorded at each station with a Seabird 25 CTD.

Two litre samples for heavy metal analysis were drawn from each sampler and filtered in a portable clean bench through pre-cleaned and tared 0.4 micron Nuclepore filters into cleaned 2 litre polyethylene sample storage bottles. When the Nuclepore filter clogged, the volume filtered was recorded and the remaining water filtered with a clean 0.4 µm Aquaprep filter. The Nuclepore filters were rinsed with 100 ml of Milli-Q water to remove salt and air dried in the portable clean bench. The filtered water samples were acidified in the BIO clean lab with 1.0 ml of Seastar sub-boiling distilled HNO_3 per litre. The Nuclepore filters were reweighed in the clean lab for gravimetric determination of suspended particulate matter (SPM) concentrations and stored at room temperature until processed for particulate metal analysis. Unfiltered water samples for total mercury analysis were drawn from the samplers into acid cleaned, 500 ml Teflon bottles and preserved with 1 ml of 0.2N BrCl in the clean bench. Unfiltered samples for salinity and nutrient analysis were also collected; the nutrient samples were stored frozen.

The water samples for Cd, Cu, Fe, Pb, Ni and Zn analyses were first heated in an oven at 60°C for a minimum of 12 hours. The metals were then extracted using an APDC/DDDC Freon extraction procedure and back extracted into HNO_3 (Dalziel et al., 1989). The extracted samples were analysed using graphite furnace atomic absorption spectrophotometry with Zeeman background correction. Manganese was analysed by direct injection into the spectrophotometer. All analytical steps were conducted in our clean room using our normal QA/QC protocols, including analysis of National Research Council of Canada (NRCC) certified reference materials (CRMs).

Samples for total Hg analysis were first heated to 60°C for 24 hours to ensure complete oxidation to Hg^{2+}. A 250ml of sample plus 0.5mL of $NH_2OH \cdot HCl$ and 1ml of $SnCl_2$ were added to a gas purging reaction vessel and the Hg^0 purged from the vessel onto an Au trap with N_2 for 30 min. After drying, the Hg on the Au trap was analysed by cold vapour atomic fluorescence spectrophotometry.

Filters for particulate metal analysis were digested in our clean lab with 2ml of Seastar HNO_3 and 1ml of HF in precleaned Loran Teflon digestion bombs and heated in a microwave oven for 45 sec. The samples were taken to dryness after digestion and redissolved in 20ml of 2% HNO_3 for analysis by inductively coupled plasma mass spectrometry (ICPMS) at a contract lab (RPC, Fredericton, NB). Filter blanks and 2-6 mg samples of NRCC BCSS-1 sediment CRM were digested and analysed using the same protocols.

RESULTS

Results from the 1999 survey are summarized in Table 1 as average concentrations in surface (1 m) and deep samples (5-15 m) for 4 regions of the harbour going from the Sydney River estuary (SRE), through the most intensely developed Central South Arm of Sydney Harbour (CSA), to the

Table 1 Average (arithmetic mean) concentrations for the October 1999 survey.

Sampling Depth	**SRE 1 m**	**SRE 5-8 m**	**CSA 1 m**	**CSA 10-14 m**	**OSA 1 m**	**OSA 10-15 m**	**OH 1 m**	**OH 9-12 m**	**NWA 1 m**	**NWA** 6-10 m
Salinity	23.76	28.50	28.43	28.67	27.88	29.06	28.47	29.33	27.86	28.73
Cd_d (ng/l)	14	19	23	24	22	23	24	32	22	25
Cu_d (µg/l)	0.63	0.42	0.51	0.43	0.55	0.33	0.44	0.33	0.48	0.42
Fe_d (µg/l)	14.8	2.87	3.22	2.91	3.40	1.45	1.67	1.14	2.67	1.78
Mn_d (µg/l)	16.7	8.4	11.0	7.6	6.4	3.9	4.8	4.1	4.8	4.0
Ni_d (µg/l)	0.46	0.36	0.57	0.38	0.42	0.31	0.36	0.45	0.45	0.45
Pb_d (ng/l)	27	13	41	21	28	23	27	17	42	26
Zn_d (µg/l)	0.64	0.34	1.88	1.50	1.30	0.56	0.42	0.32	0.90	0.51
Hg_t (ng/l)	0.77	0.53	0.51	0.36	0.34	0.56	0.43	0.25	0.43	0.24
NO_3 (µM)	2.60	0.35	0.60	0.62	0.88	0.71	0.69	0.80	0.88	0.78
NO_2 (µM)	0.25	0.11	0.24	0.22	0.20	0.18	0.19	0.16	0.17	0.20
NH_3 (µM)	5.25	2.27	3.62	3.15	2.74	2.24	1.90	1.60	1.91	2.18
HPO_4 (µM)	1.07	0.60	1.24	1.17	1.07	0.93	0.94	0.68	0.99	0.96
SiO_2 (µM)	10.40	2.54	4.41	3.95	4.59	3.61	3.72	3.02	4.10	3.67
SPM (mg/l)	1.58	1.52	1.25	1.27	1.46	1.69	2.44	4.19	1.44	1.56
Al_p (%)	5.9	5.7	2.7	3.6	5.2	8.0	8.8	11.0	4.6	6.9
Cd_p (µg/g)	0.72	1.24	1.18	0.92	0.60	0.66	0.72	0.59	0.74	0.75
Cu_p (µg/g)	107	49	78	48	66	43	63	37	48	41
Fe_p (%)	7.4	6.1	3.3	3.1	5.1	6.2	6.8	7.1	4.3	6.0
Pb_p (µg/g)	131	95	125	92	98	66	72	42	77	85
Li_p (µg/g)	42	39	34	36	43	61	57	65	31	52
Mn_p (mg/g)	4.8	6.5	4.4	3.8	4.5	2.9	2.8	1.3	3.9	4.5
Ni_p (µg/g)	29	27	29	28	32	38	41	36	26	33
Ag_p (µg/g)	0.64	0.52	0.79	0.71	0.43	0.41	0.51	0.41	0.28	0.22
Zn_p (µg/g)	289	175	342	177	188	159	137	127	165	140

SRE=Sydney River estuary, CSA=central South Arm, OSA=outer South Arm, OH=outer harbour, NWA=North West Arm.

Outer South Arm (OSA) and the Outer Harbour (OH), as well as the North West Arm (NWA) (see Fig 1 for the boundaries of these regions). Muggah Creek discharges into the CSA.

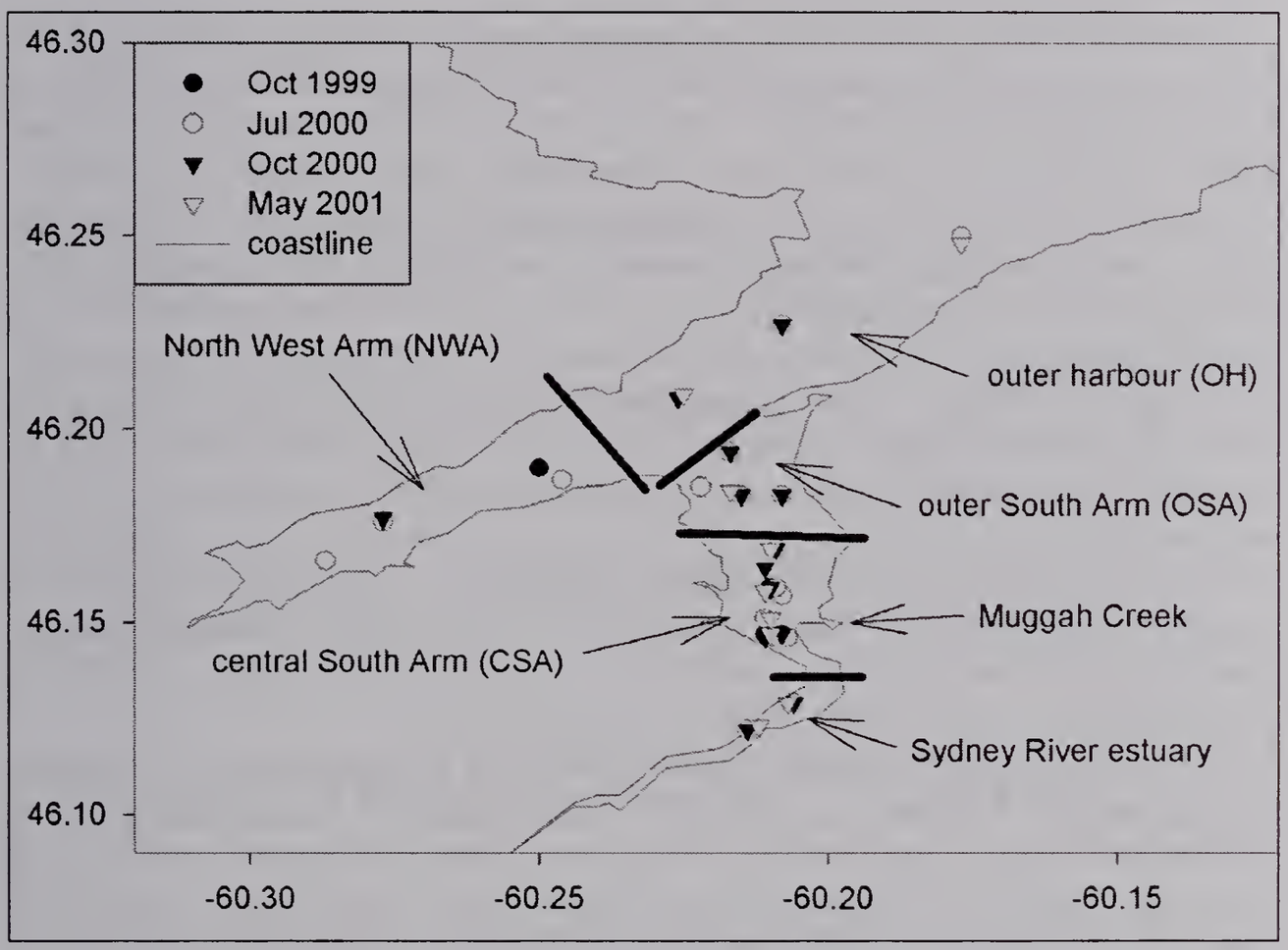

Fig 1 Map of Sydney Harbour, N.S. showing station locations and sub-region boundaries.

The salinity data in Table 1 indicated a weak estuarine pattern – salinities increased with depth in each box, and increased in both the surface and deep layers from the estuary to the outer harbour. Physical oceanographic studies showed that the general circulation pattern in Sydney Harbour was estuarine although large pulses of water into and out of the harbour (seiches) frequently overwhelmed the estuarine circulation (Petrie et al. 2001). The dissolved metal and nutrient results showed some stronger gradients, notably for Fe, Mn, NH_3 and SiO_2. The numbers of stations for each harbour region were very small (2 for SRE and OH, 4 for OSA and 5 for CSA) so it is difficult to get a good estimate of the precision of each of the arithmetic means. Based on estimates for harbour regions with larger numbers of samples, it would appear that one standard deviation precisions of the means were approximately 10-30% for Cd, Cu and Ni and 30-50% for Fe, Mn, Pb and Zn. The metal content of the particulate matter showed less variability. Particulate metal concentrations are expressed as weight of metal per gram of SPM, concentrations per litre of water can be calculated

by multiplying the metal content of the SPM by the SPM concentration. The calculations show that the particulate Cd, Cu and Ni only contributed a small percentage of the total metal concentration, but for Mn and Zn, dissolved and particulate metal concentrations were approximately equal. For Fe and Pb, the particulate dominated.

The results for the July 2000 survey are shown in Table 2. In this case the horizontal gradients in salinity were weaker, although all areas showed an increase in salinity with depth. Concentrations of the nutrients were lower than in the 1999 survey. All of these observations were consistent with lower freshwater inputs and greater biological activity that would be expected in July. One interesting difference between the October 1999 and July 2000 surveys was that concentrations of Fe, Mn, Zn and all five nutrients in July 2000 increased with depth in the CSA and OSA. Increases with depth were not evident in October 1999 except for NO_3^-. A multivariate analysis of the nutrient and metal data for these two cruises using salinity and depth as variables showed that there was a significant negative correlation ($P<0.05$) with salinity for Cu, Fe, Mn, Hg, SiO_2, NO_3^-, NH_3 and NO_2^- in the 1999 data but a positive correlation with depth only for NO_3^-. Cu and Pb showed a significant negative correlation with depth. In July 2000, there was a negative correlation with salinity only for Mn and Si, but a positive correlation with depth for Fe, Mn, SiO_2, HPO_4^{2-}, NO_3^- and NO_2^-.

The October 2000 survey (Table 3) shows virtually uniform salinities throughout the harbour, i.e. very little stratification or horizontal gradient. Freshwater input to the harbour at the time of this survey was very low, so metal concentrations in the harbour should more clearly reflect anthropogenic inputs, but concentrations in the CSA and OSA were relatively low and not significantly elevated compared to the other surveys.

The final survey in May 2001 was conducted at a time of much higher freshwater input. The results (Table 4) show much greater vertical and horizontal gradients in salinity as well as higher concentrations of Fe and especially Mn in the estuary surface samples. Despite the greater freshwater inputs, concentration increases with depth in CSA and OSA are evident for Mn, NH_3 and HPO_4^{2-}. The multivariate analysis shows significant ($P<0.05$) negative correlation with salinity for Cd, Cu, Fe, Mn, Hg, SiO_2, NO_3^- and NH_3, and positive correlations with depth for Mn, HPO_4^{2-}, NO_3^- and NH_3.

DISCUSSION

The first objective of this study was to establish the contaminant exposure levels and assess the potential toxicity of water column metals in Sydney Harbour. There are very few Canadian environmental guidelines or regulations for the concentrations of heavy metals in estuarine or marine waters. The only marine water quality guideline for protection of aquatic life given in the Canadian Council of Ministers of the Environment (CCME 2001) Environmental Quality Guidelines for the metals described in this paper is the limit of 0.12 µg/l for Cd. The guideline refers to total Cd in the water,

Table 2 Average (arithmetic mean) concentrations for the July 2000 survey.

Sampling Depth	SRE 1 m	SRE 5-9 m	CSA 1 m	CSA 10-15 m	OSA 1 m	OSA 12-17 m	OH 1 m	OH 10-14 m	NWA 1 m	NWA 7-9 m
Salinity	27.54	29.29	29.62	30.09	29.68	30.16	29.89	30.10	29.59	29.97
Cd_d (ng/l)	19	23	24	23	29	25	22	14	30	29
Cu_d (µg/l)	0.54	0.47	0.41	0.33	0.51	0.29	0.34	0.25	0.32	0.29
Fe_d (µg/l)	3.33	2.59	2.04	4.28	1.88	3.99	0.75	0.71	3.72	2.47
Mn_d (µg/l)	11.8	10.3	7.1	9.3	6.9	9.5	3.7	2.6	6.3	6.9
Ni_d (µg/l)	0.35	0.33	0.36	0.31	0.33	0.31	0.30	0.29	0.27	0.32
Pb_d (ng/l)	8	8	15	10	8	8	12	12	13	8
Zn_d (µg/l)	0.68	1.13	1.61	1.31	0.88	1.17	0.36	0.35	0.45	0.43
Hg_t (ng/l)	0.36	0.35	0.48	0.42	0.28	0.41	0.25	0.21	0.23	0.21
NO_3 (µM)	0.19	0.13	0.22	0.42	0.06	0.25	0.08	0.10	0.11	0.25
NO_2 (µM)	0.11	0.10	0.12	0.17	0.08	0.13	0.10	0.10	0.08	0.12
NH_3 (µM)	0.32	0.34	0.65	1.02	0.60	0.84	0.10	0.10	0.48	0.65
HPO_4 (µM)	0.90	0.72	0.74	1.02	0.58	1.01	0.55	0.54	0.62	0.81
SiO_2 (µM)	8.20	5.19	4.41	6.73	3.23	6.48	2.08	2.73	2.98	4.97
SPM (mg/l)	1.60	1.09	1.32	1.97	1.67	1.06	0.69	0.79	0.90	1.54
Al_p (%)	1.8	1.8	2.2	2.4	1.7	3.5	3.3	4.2	2.4	2.3
Cd_p (µg/g)	1.52	1.87	1.43	0.93	1.24	1.45	1.54	1.16	1.27	0.78
Cu_p (µg/g)	56	45	52	33	33	29	42	37	19	26
Fe_p (%)	3.5	3.9	3.1	5.0	1.6	4.5	2.4	2.7	2.1	2.6
Pb_p (µg/g)	89	94	100	83	55	74	62	38	68	47
Li_p (µg/g)	16	16	18	20	15	29	28	36	21	22
Mn_p (mg/g)	5.3	5.8	2.9	2.7	2.7	2.2	2.9	2.0	3.2	2.1
Ni_p (µg/g)	83	11	14	9	16	32	32	35	12	31
Ag_p (µg/g)	1.13	0.89	0.64	0.45	0.31	0.42	0.29	0.26	0.36	0.29
Zn_p (µg/g)	234	198	149	148	110	155	94	112	99	117

SRE=Sydney River estuary, CSA=central South Arm, OSA=outer South Arm, OH=outer harbour, NWA=North West Arm.

Table 3 Average (arithmetic mean) concentrations for the October 2000 survey.

Sampling Depth	SRE 1 m	SRE 5-9 m	CSA 1 m	CSA 12-16 m	OSA 1 m	OSA 15-16 m	OH 1 m	OH 11-15 m	NWA 1 m	NWA 11 m
Salinity	28.99	29.04	29.03	29.20	29.19	29.20	29.05	29.16	29.18	19.19
Cd_d (ng/l)	19	20	24	20	16	20	22	18	21	16
Cu_d (µg/l)	0.67	0.47	0.55	0.36	0.45	0.34	0.47	0.36	0.37	0.33
Fe_d (µg/l)	2.50	2.73	2.77	3.42	1.94	2.68	1.71	1.65	1.43	1.85
Mn_d (µg/l)	5.62	5.06	5.7	5.4	2.5	4.3	2.05	2.91	1.8	2.4
Ni_d (µg/l)	0.26	0.24	0.29	0.27	0.28	0.26	0.28	0.27	0.27	0.26
Pb_d (ng/l)	34	19	33	18	10	7	26	13	11	5
Zn_d (µg/l)	1.58	1.01	0.98	0.76	0.98	0.58	0.80	0.45	0.25	0.18
Hg_t (ng/l)	0.56	0.62	0.53	0.40	0.45	0.38	0.45	0.39		
NO_3 (µM)	0.81	0.78	0.69	0.52	0.46	0.46	0.21	0.22	0.19	0.31
NO_2 (µM)	0.33	0.36	0.28	0.29	0.25	0.25	0.17	0.17	0.19	0.24
NH_3 (µM)	3.07	3.35	2.71	3.36	1.48	2.06	0.54	0.46	0.40	1.18
HPO_4 (µM)	1.36	1.54	1.53	1.29	1.35	1.13	0.69	0.82	1.03	1.11
SiO_2 (µM)	7.25	6.96	7.22	7.16	6.74	7.09	3.72	4.16	5.83	6.50
SPM (mg/l)	1.69	1.78	1.03	0.89	0.82	0.85	0.89	1.32	1.62	0.55
Al_p (%)	2.2	2.3	1.8	2.8	2.3	3.9	2.9	3.2	1.8	3.3
Cd_p (µg/g)	0.92	1.05	0.96	1.50	1.15	2.50	1.02	0.56	0.76	0.80
Cu_p (µg/g)	186	87	66	53	53	68	100	31	28	32
Fe_p (%)	3.1	3.1	3.3	3.9	3.4	4.0	2.2	2.6	1.7	3.0
Pb_p (µg/g)	142	134	121	102	98	84	68	42	54	68
Li_p (µg/g)	21	23	16	25	21	33	25	29	16	31
Mn_p (mg/g)	8.4	8.7	10.1	9.3	10.9	8.9	3.5	4.0	4.7	6.4
Ni_p (µg/g)	24	21	47	41	37	27	48	48	14	23
Ag_p (µg/g)	1.35	1.44	0.79	0.90	0.74	0.92	0.53	0.45	0.29	0.58
Zn_p (µg/g)	223	238	568	315	174	241	84	104	63	89

SRE=Sydney River estuary, CSA=central South Arm, OSA=outer South Arm, OH=outer harbour, NWA=North West Arm.

Table 4 Average (arithmetic mean) concentrations for the May 2001 survey.

Sampling Depth	SRE 1 m	SRE 7-9 m	CSA 1 m	CSA 10-15 m	OSA 1 m	OSA 16-17 m	OH 1 m	OH 12-14 m
Salinity	20.60	29.42	22.87	29.76	23.66	32.25	26.84	32.30
Cd_d (ng/l)	26	22	25	26	24	25	21	19
Cu_d (µg/l)	0.59	0.30	0.50	0.27	0.57	0.23	0.48	0.20
Fe_d (µg/l)	13.80	1.71	6.60	2.05	9.48	2.18	2.87	1.24
Mn_d (µg/l)	31.85	18.15	25.73	35.93	24.95	37.40	13.60	9.09
Ni_d (µg/l)	0.23	0.29	0.34	0.30	0.30	0.25	0.33	0.20
Pb_d (ng/l)	40	2	21	16	24	8	38	12
Zn_d (µg/l)	1.99	1.57	7.78	7.71	12.44	1.82	3.74	1.54
Hg_t (ng/l)	1.41	0.44	1.12	0.33	1.05	0.39	0.62	0.28
NO_3 (µM)	1.35	0.10	0.79	0.30	0.54	0.14	0.07	0.06
NO_2 (µM)	0.10	0.06	0.08	0.07	0.06	0.04	0.06	0.08
NH_3 (µM)	1.57	0.86	0.77	1.61	1.10	1.32	0.22	0.76
HPO_4 (µM)	0.23	0.33	0.19	0.56	0.14	0.49	0.29	0.42
SiO_2 (µM)	7.34	0.69	5.49	0.90	4.69	0.67	1.77	0.50
SPM (mg/l)	1.42	0.78	1.44	0.80	1.19	0.59	1.10	0.86
Al_p (%)	3.2	4.6	3.0	2.4	2.8	3.0	5.0	3.8
Cd_p (µg/g)	0.72	0.23	0.66	0.86	0.56	0.92	0.32	0.25
Cu_p (µg/g)	72	29	40	21	62	21	28	28
Fe_p (%)	3.3	3.6	3.0	2.3	3.3	2.7	3.7	2.7
Pb_p (µg/g)	42	45	41	32	60	30	48	21
Li_p (µg/g)	26	38	23	20	26	24	40	36
Mn_p (mg/g)	0.92	1.37	1.00	0.88	1.33	1.12	1.12	0.96
Ni_p (µg/g)	38	31	31	20	66	23	38	28
Ag_p (µg/g)	0.85	0.49	1.05	.40	0.96	0.12	0.93	0.58
Zn_p (µg/g)	126	113	531	313	478	133	281	127

SRE=Sydney River estuary, CSA=central South Arm, OSA=outer South Arm, OH=outer harbour.

so we need to compare the sum of measured dissolved and particulate Cd to the guideline. The maximum total Cd concentration seen in all of our surveys was 0.061 µg/l (0.059 µg/l dissolved + 0.002 µg/l particulate), i.e. only half of the guideline concentration. Average concentrations of dissolved plus particulate Cd in Sydney Harbour (Tables 1-4) were less than 25% of the guideline.

Other jurisdictions give guidelines for some of the other metals. For example, the Australia and New Zealand Environment and Conservation Council (ANZECC 2000) gives guidelines for the protection of aquatic ecosystems that includes, at the most stringent level of protection (99% of test species), 0.7 µg/l for Cd, 0.3 µg/l for Cu, 2.2 µg/l for Pb, 0.1 µg/l for Hg, 7 µg/l for Ni and 7 µg/l for Zn. The European Union (EU) guidelines are 0.1 µg/l for Cd, 5 µg/l for Pb, 0.05 µg/l for Hg and 5 µg/l for Zn. The EU Cu guideline (0.05 µg/l) is not appropriate because it refers to free ionic Cu, not total dissolved Cu. US guideline levels are generally higher. Eighty-three percent of our samples were above the most stringent ANZECC Cu guideline, but all samples were below the ANZECC guideline for protection of 95% of test species and the US guideline. Also, it is not clear that marine

guidelines established for open coastal waters would be appropriate for the lower salinities found in estuaries. If we estimate salinity dependent estuarine guidelines based on linear interpolations between the ANZECC freshwater and marine guidelines, only 3 of the Sydney Harbour Cu samples would be above this 'guideline'. Four of the samples from the May 2001 survey exceeded the ANZECC Zn guideline of 7 µg/l, but all were below the guidelines from the US and EU, and as noted above for Cu, they would be below an estuarine guideline interpolated between the freshwater and seawater guidelines. Zn concentrations of samples from the other three surveys were all below the guidelines.

It is difficult to accurately assess the toxicity of Cu because of the difference in toxicity between ionic Cu (highly toxic) and organically complexed Cu (much less toxic). Bioavailability would also be reduced for Cu complexed to terriginous organic matter (e.g. humic and fulvic acids). Ionic Cu was used in most of the laboratory toxicity tests upon which the guidelines are based, but in estuarine and marine environments most of the Cu would be complexed. Organic complexation probably eliminates any potential Cu toxicity for the Sydney Harbour waters.

The consistency in the picture of metal distributions observed from one survey to the next bodes well for establishing the usefulness of the data presented in Tables 1-4 for meeting the second objective of the project, i.e. to provide data for ground-truthing of water quality models. It would be difficult to relate highly variable measurements of the concentrations to the monthly or seasonally averaged descriptions of water circulation and water quality that are being developed, but the data presented in the tables show relatively little variability from survey to survey and muted gradients within the surveys.

The main sources of heavy metals in Sydney Harbour are the natural freshwater input (~$1x10^6$ m^3/day) and the various anthropogenic inputs including outflow from the Sydney Tar Ponds and the many untreated municipal/industrial sewage/storm water discharges (~$2x10^4$ m^3/day). Water entering the harbour from the offshore as a result of the estuarine circulation also brings heavy metals into the harbour. Most of the natural freshwater input is from the Sydney River into the SRE. The two largest sewer inputs are ~$8x10^3$ m^3/day into the CSA through Muggah Creek (also the point of entry for input from the Tar Ponds) and ~$6x10^3$ m^3/day into the SRE near Wentworth Creek. The next largest sewers (~$3x10^3$ m^3/day at Dobsons Point and ~$1x10^3$ m^3/day at Sydport) discharge into the CSA (CBCL 1999). The relative importance of these sources for the various dissolved metals are evident from the data presented in Table 1 and illustrated in the plots of metal concentration vs. salinity for the October 1999 survey (Fig 2). For Fe, the distribution was clearly controlled by input from the rivers, dilution with seawater within the harbour and removal by chemical precipitation, although some indication of additional inputs to the CSA was evident. For Cu, Mn, Ni, Pb and Zn inputs from both the natural and anthropogenic sources were important. The freshwater source was relatively more important for

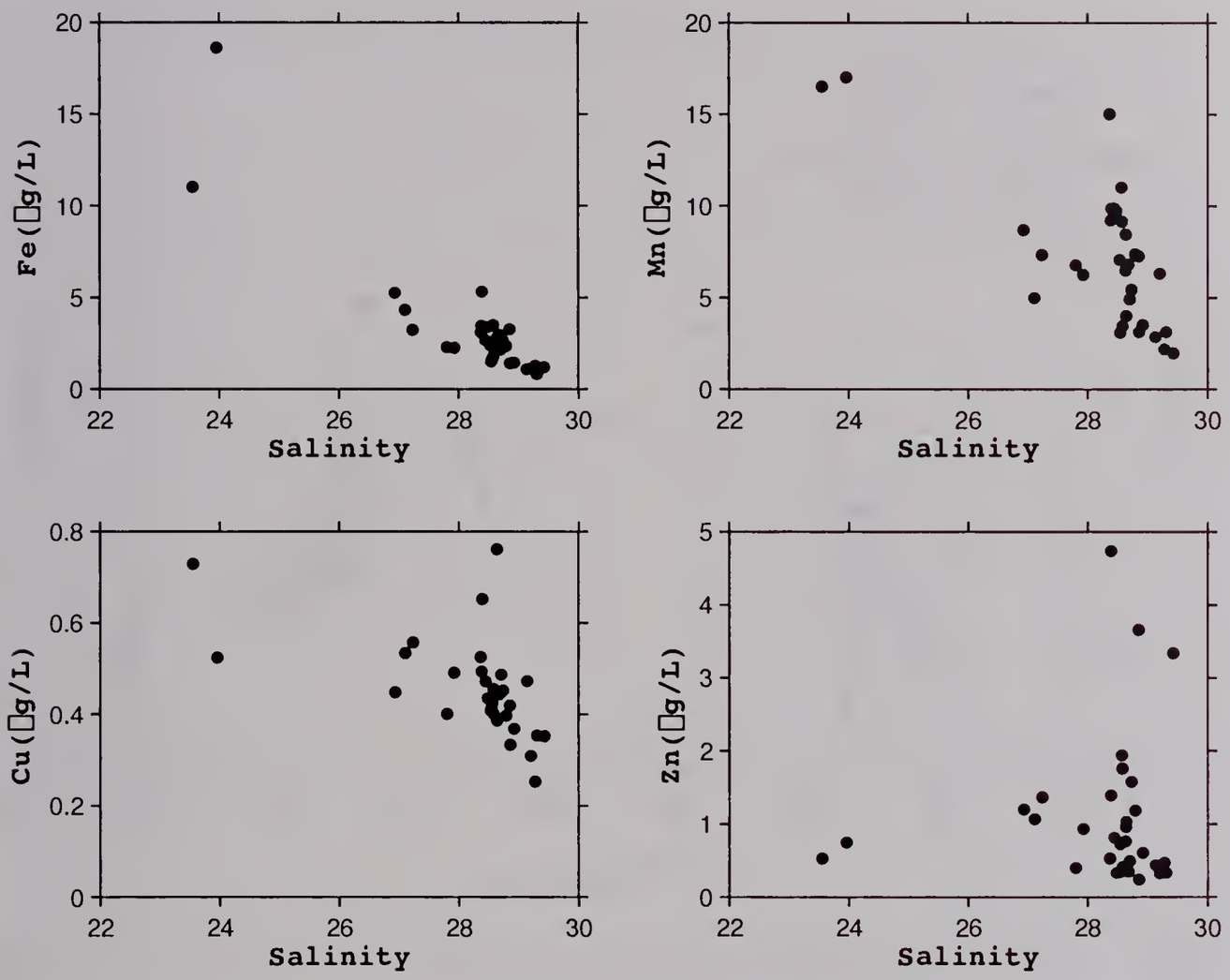

Fig 2 Metal vs. salinity relationships for the October 1999 survey.

Mn and Cu than for Ni and Pb and least important for Zn. Inputs from the two types of sources can be seen in all the plots of concentration vs. salinity where elevated concentrations in the CSA (anthropogenic inputs) were superimposed on a general decrease in concentration with salinity (natural freshwater input). For Mn and Zn, the elevated samples included CSA and OSA samples from both surface and deep layers while for Cu, Ni and Pb, the elevated concentrations were restricted to a few surface layer samples. Similar patterns were seen for the nutrients where natural freshwater inputs dominated for SiO_2 and NO_3^-, with anthropogenic sources increasingly important for NO_2^-, HPO_4^{2-} and NH_3. There is a very strong covariance of the Mn and NH_3 concentrations (r=0.881). It would appear that these two parameters are the strongest markers for the sewage input to the harbour. Data collected by Environment Canada on metals in sewage showed elevated average Mn concentrations of 248 µg/l for the Wentworth discharge and 361 µg/l for the Muggah Creek discharge (Julien 2002). Cd concentrations increased with increasing salinity, pointing to the importance of offshore waters as a source for the Cd in the harbour waters.

For the July and October 2000 surveys the observed salinity ranges were reduced but the basic metal vs. salinity relationships remained much the same. The only significant differences were that elevated concentrations were also observed in the OSA and were more restricted to the bottom

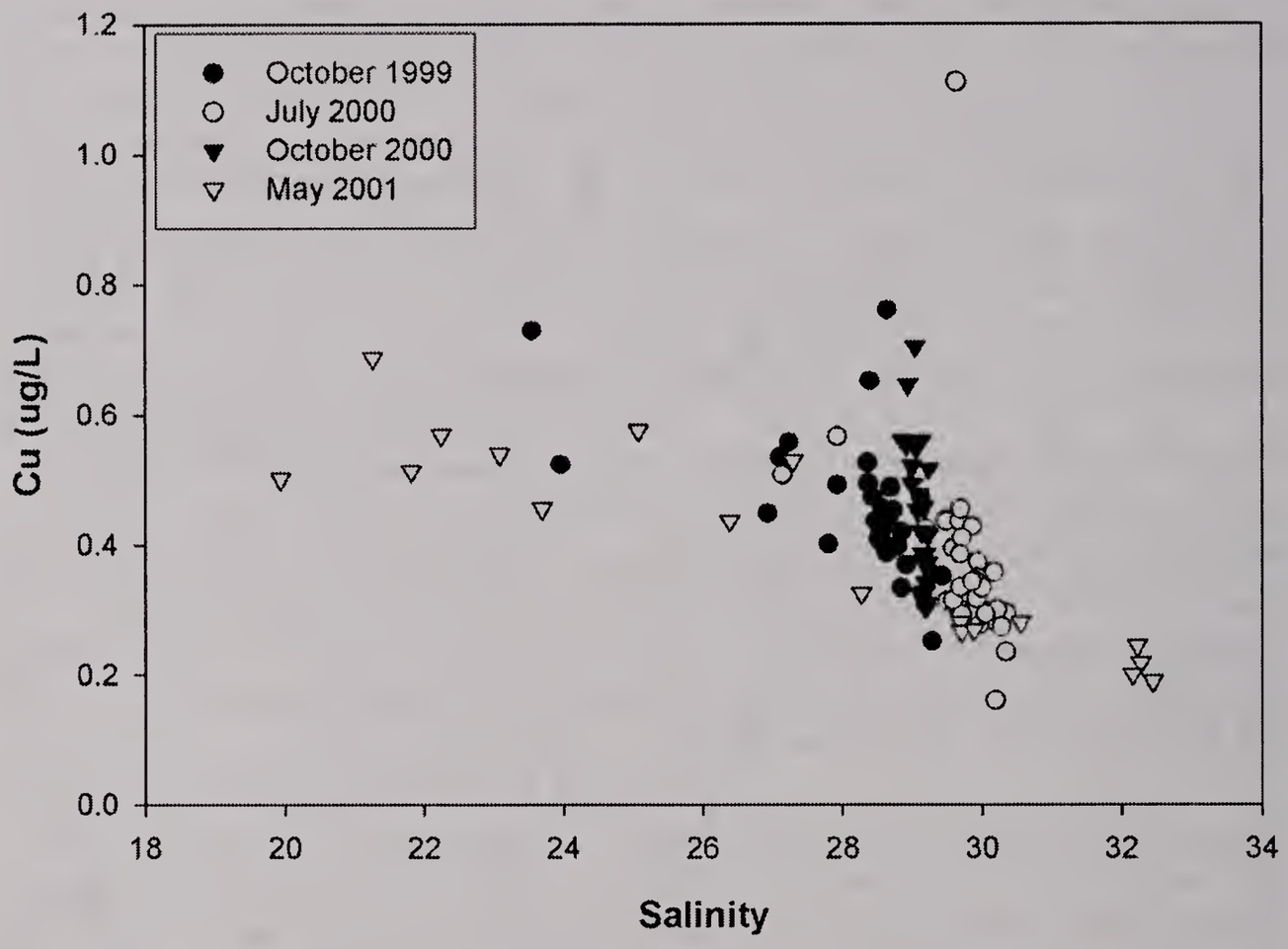

Fig 3 Combined Cu vs. salinity plot for all four surveys.

waters. These differences were also evident in the average concentrations listed in Tables 1-4. The nutrients followed very similar patterns. The absolute concentrations were reduced in the July survey presumably as a result of biological activity but all showed the decreasing concentrations with increasing salinity and positive anomalies for predominantly bottom water samples for the CSA and OSA, i.e. the same pattern as seen for Fe, Mn and Zn.

The final, more limited survey in May 2001 found a much greater range in salinity (spring runoff), general decreases in concentrations of Cu, Fe, Mn, NO_3^-, NH_3 and SiO_2 with increasing salinity and elevated concentrations in bottom waters of CSA and OSA for Mn, NH_3 and HPO_4^{2-}, basically the same pattern as seen on the other cruises. The survey to survey comparability is sufficiently good that all the data can generally be described by single metal salinity relationships, such as for Cu shown in Fig 3.

The four Zn results from the May 2001 survey that exceeded the ANZECC water quality guideline were found in the CSA (1 surface and 2 deep) and OSA (1 surface). Anomalously high Cu samples, when observed, were always CSA or OSA surface samples. Pb anomalies also tended to be surface samples, but for Fe, Mn and the nutrients, results that were above the parameter vs. salinity regression lines were predominantly deep samples. This distinction is interesting; surface runoff including the overflow from the Tar Ponds is into the surface layer but sewage inputs are, initially at

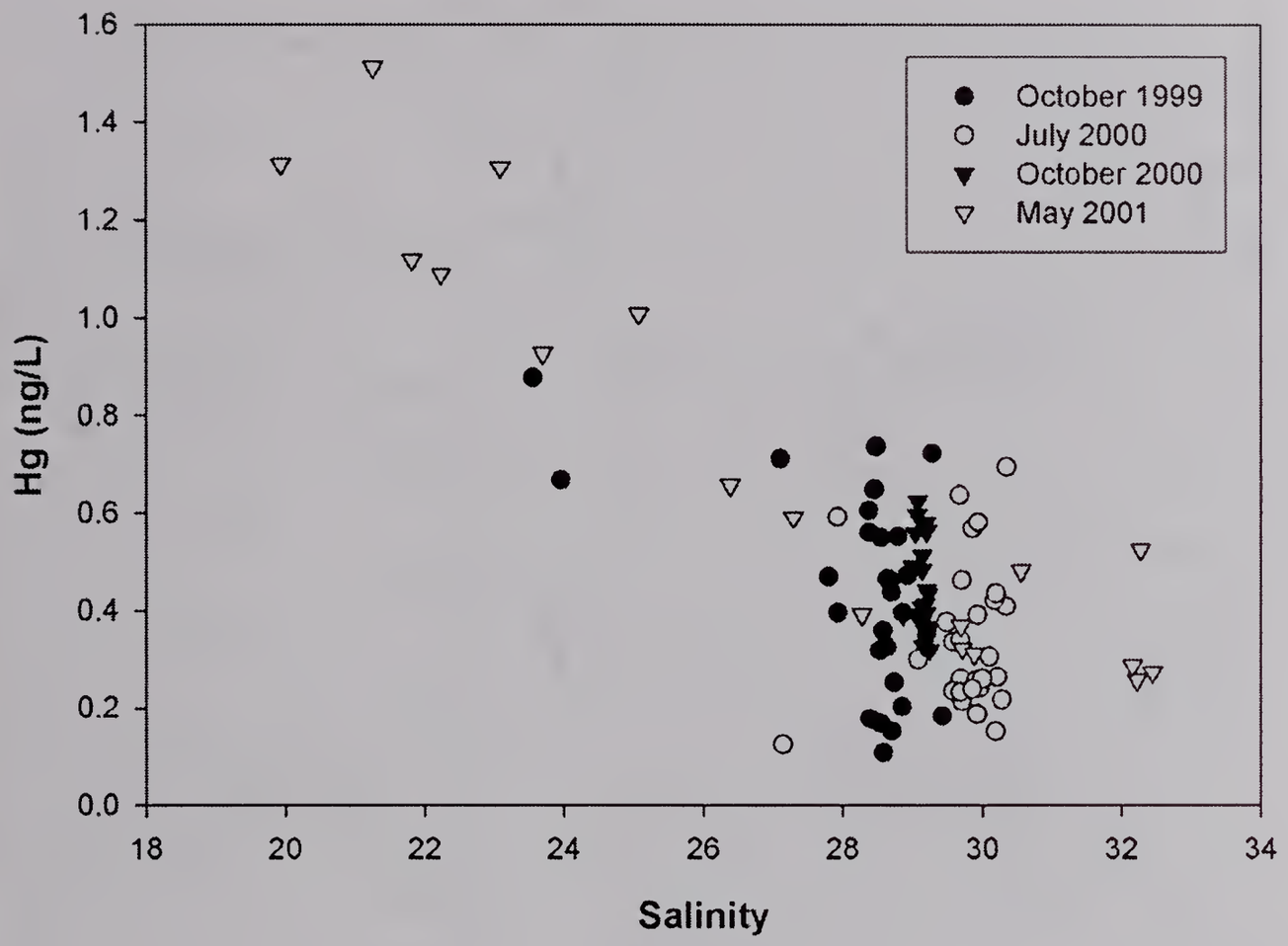

Fig 4 Total mercury vs. salinity relationship for Sydney Harbour.

least, into the deep layer because the sewage discharge points are generally submerged. Discharges do not have to be very deep to be into the deep layer because the surface layer in Sydney Harbour is very thin (~ 2 m). Buoyancy of the sewage (its salinity is much lower than the estuarine receiving waters) should rapidly bring the dissolved sewage constituents to the surface. The elevated dissolved metal and nutrient concentrations in the deeper water likely resulted from the release from the sediments of metals and nutrients from the anaerobic decomposition of organic matter (mostly derived from sewage) in the sediments.

The total Hg distributions showed less indication than those of Cu, Pb, Mn or Zn of additional inputs into the central part of the harbour. The Hg_t vs. salinity plot for the May 2001 survey (Fig 4) shows an essentially linear decrease in Hg concentration with increasing salinity, and the plot combining all the data from the four surveys shows little indication of elevated concentrations in the CSA.

SPM concentrations in Sydney Harbour (0.5-2.0 mg/l) were generally low compared to estuaries elsewhere (e.g. Postma 1980). As a result, the contribution of particulates to the total metal concentrations was lower than expected for estuaries. The heavy metal content of the particulate matter (Fig 5) showed a general background of inorganic particulates, with many samples from the SRE, CSA and OSA having higher heavy metal content. Background concentrations in Fig 5 were estimated from the metal vs. Li

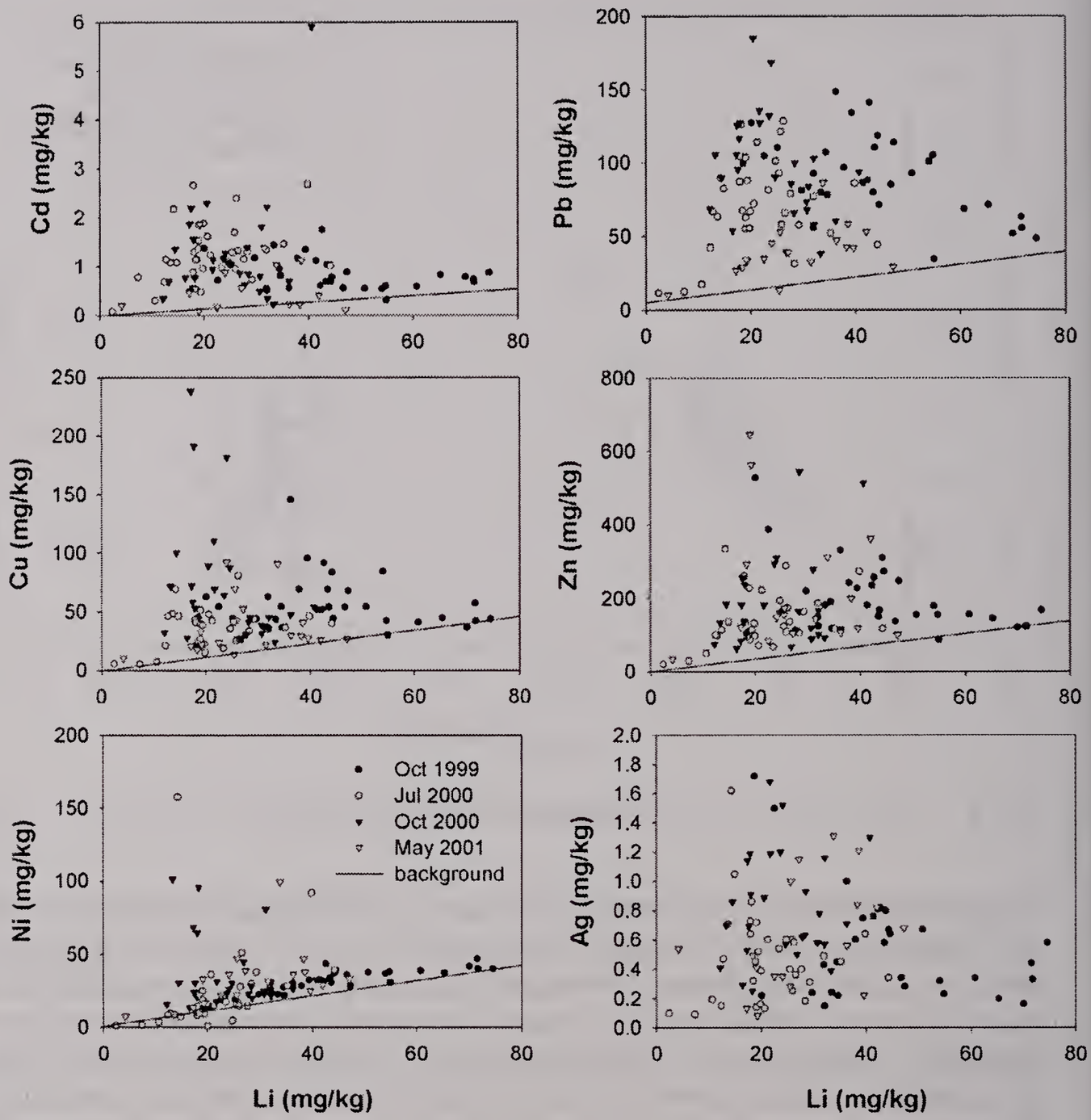

Fig 5 Metal vs. Li relationships for SPM samples from Sydney Harbour. Regression lines in the figure refer to background metal vs. Li relationships for unpolluted N.S. coastal sediments.

relationships found for estuarine sediments in harbours and inlets around Nova Scotia using Li as a grain-size normalizer (Loring 1990).

Ag concentrations in sediments have been shown to be good indicators of sewage input (Ravizza & Bothner 1996). In Sydney Harbour maximum sediment Ag concentrations (Loring et al. 2008) were seen adjacent to the two largest sewage discharges. Ag content of the SPM samples (Fig 5) showed a rather similar pattern to those of Cd, Cu, Pb and Zn suggesting, perhaps, a common sewage source for all these metals. Principal component analysis for the 29 elements that were determined for the 112 SPM samples from all four surveys (Table 5), however, showed grouping of Cr, Mo and Ni in one factor and Cu, Pb, Mn and Ag in another. If factor 1 (Al,

Table 5 Varimax matrix for metals in Sydney Harbour SPM (for P=0.01, r=0.241)

	1	2	3	4	5	6
Al	0.929					
Sb						-0.514
As					0.877	
Ba	0.459	0.317				0.539
Be	0.901					
Cd					0.389	
Ca	0.385		0.753			
Cr	0.257			0.829		
Co	0.708	0.405		0.283		
Cu		0.619		0.306		
Fe	0.766				0.444	
La	0.752					
Pb		0.820			0.253	
Li	0.966					
Mg			0.870			
Mn		0.798				
Mo		0.468		0.734		
Ni				0.843		
K	0.881		0.261			
Rb	0.957					
Ag		0.664			0.246	
Na	-0.344		0.862			
Sr		0.429	0.617			0.315
Tl	0.854					
Sn						0.558
Ti	0.767					-0.328
U	0.801					
V	0.517				0.771	
Zn					0.373	0.528
% of var.	30.621	11.164	9.227	8.500	7.498	5.555

Be, Co, Fe, La, Li, K, Rb, Tl, Ti and U) is an aluminosilicate mineral factor, and the Cu, Pb, Mn and Ag grouping (factor 2) is a sewage factor, then the PCA would suggest that other sources or processes are contributing significantly to the distributions of particulate Cd, Cr, Ni and Zn.

Four surveys between October 1999 and May 2001 of dissolved and particulate metals in Sydney Harbour waters provided a comprehensive assessment of metal distributions for the period immediately preceding efforts to clean up the Sydney Tar Ponds. Average concentrations observed in various parts of the harbour were almost always below water quality guidelines for estuarine or marine waters and showed relatively little variation from one survey to another. Observations within the harbour showed that inputs to the central part of South Arm modify distributions that generally reflect estuarine dilution of freshwater inputs. Sewage appeared to be the major but not sole source of inputs to the central South Arm.

REFERENCES

ANZECC (2000) Australia and New Zealand guidelines for fresh and marine water quality. Vol. 1 The guidelines. Australia and New Zealand Environment and Conservation Council, Paper #4

CBCL (CBCL Limited, Consulting engineers) (1999) Phase 1 site assessment, Muggah Creek watershed, Sydney, Nova Scotia. Final Report 98628B, Supply and Services Canada

CCME (Canadian Council of Ministers of the Environment) (2001) Canadian water quality guidelines for the protection of aquatic life. In: Canadian Environmental Quality Guidelines

Dalziel JA, Yeats PA, Loring DH (1989) Dissolved and particulate trace metal distributions in Halifax Harbour. In: Nichols HB (ed) Investigations of marine environmental quality in Halifax Harbour. Can Tech Rep Fish Aquat Sci 1693

Ernst WR, Pitcher D, Matthews S, Julien G (1999) Concentration and distribution of polycyclic aromatic hydrocarbons (PAHs), PCBs and metals in sediments, mussels (*Mytilus edulis* and *Modiolus modiolus*), and lobsters (*Homarus americanus*) from Sydney Harbour, Nova Scotia. Environment Canada Surveillance Report # EPS-5-AR-99-7

Julien G (2002) (Environment Canada, Dartmouth, NS) Personal communication

Loring DH (1990) Lithium - a new approach for the granulometric normalization of trace metal data. Mar Chem 29:155-168

Loring DH, Yeats PA and Milligan TG (2008) Heavy metal contamination of Sydney Harbour sediments. Proc NS Inst Sci 44(2): 153-170

Matheson RAF, Trider GL, Ernst WR, Hamilton KG, Hennigar PA (1983) Investigation of polynuclear aromatic hydrocarbon contamination of Sydney Harbour, Nova Scotia. Environment Canada, Surveillance Report EPS-5-AR-83-6

Petrie B, Bugden G, Tedford T, Geselin Y, Hannah C (2001) Review of the physical oceanography of Sydney Harbour. Can Tech Rep Hydrog Ocean Sci 215

Postma H (1980) Sediment transport and sedimentation. In: Olausson E, Cato I (eds) Chemistry and biogeochemistry of estuaries. John Wiley and Sons, Chichester, p 153-186

PWGSC (Public Works and Government Services Canada) (2005) Remediation of Sydney Tar Ponds and Coke Oven sites – Draft scoping document

Ravizza GE, Bothner MH (1996) Osmium isotopes and silver as tracers of anthropogenic metals in sediments from Massachussetts and Cape Cod Bays. Geochim Cosmochim Acta 60:2753-2763

Sirota GR, Uthe JF, Robinson DG, Musial CJ (1984) Polycyclic aromatic hydrocarbons in American lobster (*Homarus americanus*) and blue mussels *(Mytilus edulis*) collected in the area of Sydney Harbour, Nova Scotia. Can MS Rep Fish Aquat Sci 1758

Stewart PL, White L (2001) A review of contaminants on the Scotian Shelf and adjacent coastal waters: 1970 to 1995. Can Tech Rep Fish Aquat Sci 2351

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RISK ESTIMATES: POLYCYCLIC AROMATIC HYDROCARBONS IN SYDNEY HARBOUR SEDIMENTS AND LOBSTER

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For nearly a century, the effluents from the Sydney Tar Ponds were discharged into Muggah Creek. As this creek opens into the South Arm of Sydney Harbour, this discharge resulted in appreciable levels of polyaromatic hydrocarbons (PAHs) being deposited in the Harbour sediments. Because surveys showed that lobsters captured in the South Arm of the Harbour contained substantial levels of benzo[a]pyrene, a known carcinogen, the lobster fishery in the South Arm of the Harbour was closed in 1982. Prior to the closure, the cancer lifetime risk for those eating lobsters from this area was approximately 3 times greater than the provincial acceptable level. Following the closure, the lifetime cancer risk declined to levels considered to be acceptable. Computed non-cancer hazards were deemed acceptable prior to the closure and decreased following it. A more extensive risk assessment will evaluate the site further and provide valuable information on fisheries decisions for this area.

Pendant près d'un siècle, l'effluent des étangs de goudron de Sydney s'est écoulé dans le ruisseau Muggah. Comme celui-ci se jette dans le bras sud du port de Sydney, cet écoulement a abouti au dépôt de concentrations appréciables d'hydrocarbures aromatiques polycycliques (HPA) dans les sédiments du port. Les relevés ayant révélé que des homards capturés dans le bras sud du port présentaient des concentrations notables de benzoapyrène, un cancérogène notoire, la pêche du homard dans le bras sud du port a été fermée en 1982. Avant sa fermeture, le risque à vie de cancer chez les personnes qui consommaient du homard en provenance de ces eaux était trois fois supérieur au niveau acceptable établi pour la province. Après la fermeture de la pêche, le risque à vie de cancer est retombé à des niveaux considérés comme acceptables. Les risques autres que le cancer établis par calcul étaient jugés acceptables avant la fermeture de la pêche et ils ont diminué après cette fermeture. Il sera procédé à une évaluation plus exhaustive des risques, qui fournira des renseignements utiles concernant les décisions sur la pêche dans cette région.

INTRODUCTION

With industrialization in the 19th century, the rich deposits of coal in Cape Breton Island led to the construction of a steel plant in the city of Sydney. To secure supplies of coke, which played an important role in the steel making process, two coal coking facilities were constructed on the shore of Sydney Harbour beginning in 1901.

A coke-oven is essentially a large chamber where coal is heated and at a specific temperature, undesired tar and gases separate from the desired

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coke. For nearly a century the liquid effluents were discharged from the coke ovens into the "Tar Ponds"; from there some portion of the toxic effluents flowed into the harbour (Figure 1). The site in question covers 72

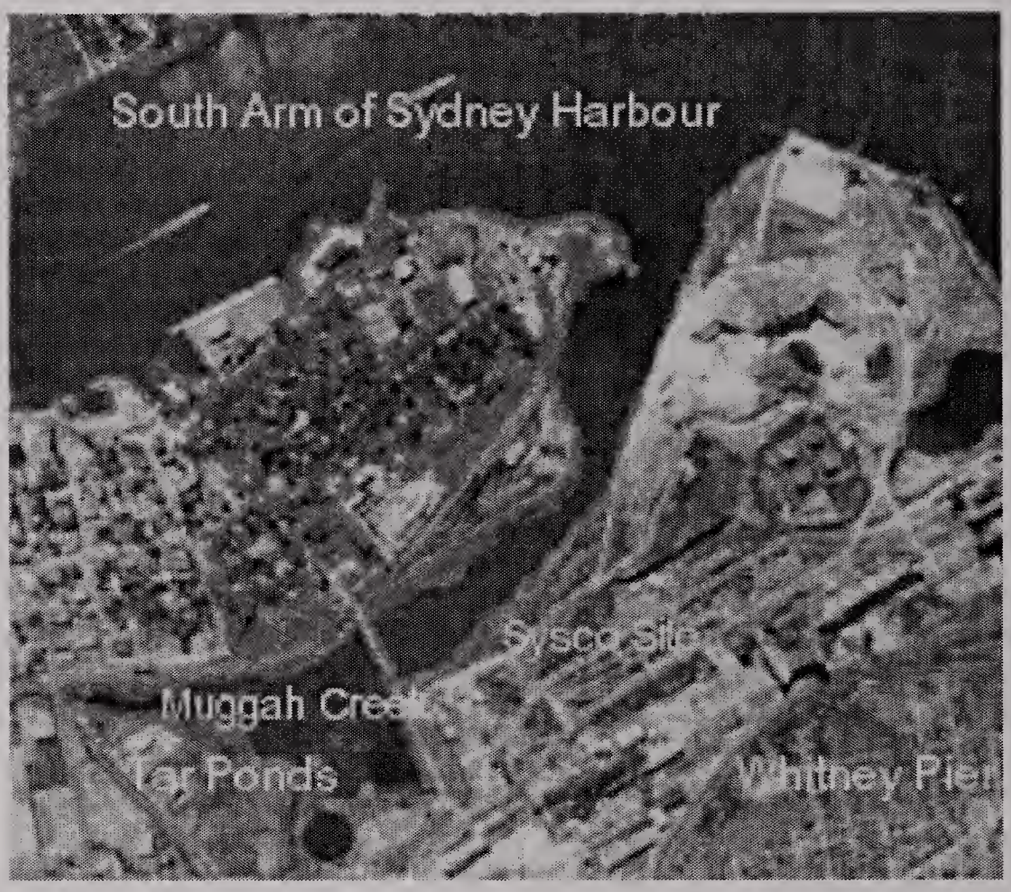

Fig 1 The Sydney Tar Ponds (Canadian Environmental Assessment Agency 2005).

hectares. The coke-oven operation contaminated the ground and surface water with arsenic, lead, and other toxins resulting in an accumulation of some 700,000 tonnes of chemical waste, mostly polycyclic aromatic hydrocarbons (PAHs) [40,000 tonnes of which are polychlorinated biphenyls (PCBs)]. About 24,000 people live in Sydney and a study concluded that cancer rates are highest among those city residents who live within 5 km of the Tar Ponds (Guernsey et al. 2000).

The two coking plants were closed, one in 1981 and the second in 1983. In the early 1980s, the South Arm of the harbour was closed to commercial lobster fishing based on the health risk associated with consuming lobster contaminated with PAHs (Uthe & Musial 1986). Many of these PAHs, such as benzo[a]pyrene (B[a]P), a known carcinogen, were found in the edible tissue of the animal. Lobsters were re-surveyed in 1995 and in addition to the commonly measured PAHs, a multitude of complex unknown peaks were found (King et al 1993). There is still lobster fishing in other parts of the harbour: 52 fishing vessels set as many as 4300 traps per day during the fishing season (Prouse 1994). The seasonal catch amounts to >200,000 lbs.

In order to assess the human health risk involved in consuming contaminated seafood it was necessary to: 1) select a commercial species which

is easy to sample, 2) select a fishery near or in a contaminated site. For this study American lobster (*Homarus americanus*), a highly desirable food stuff, was selected, because it has a large economic commercial value and was easy to sample. The site selected was the South Arm of Sydney Harbour, because it was near the Sydney Tar Ponds. In addition a remote clean second site, St. Margarets Bay of Nova Scotia was selected as a control site.

MATERIALS AND METHODS

Sampling

South Arm of Sydney Harbour

Sampling was carried out in October 2001 on the CCGS Navicula. Grab samples were taken from 20 stations (Figure 2). At each station, when suf-

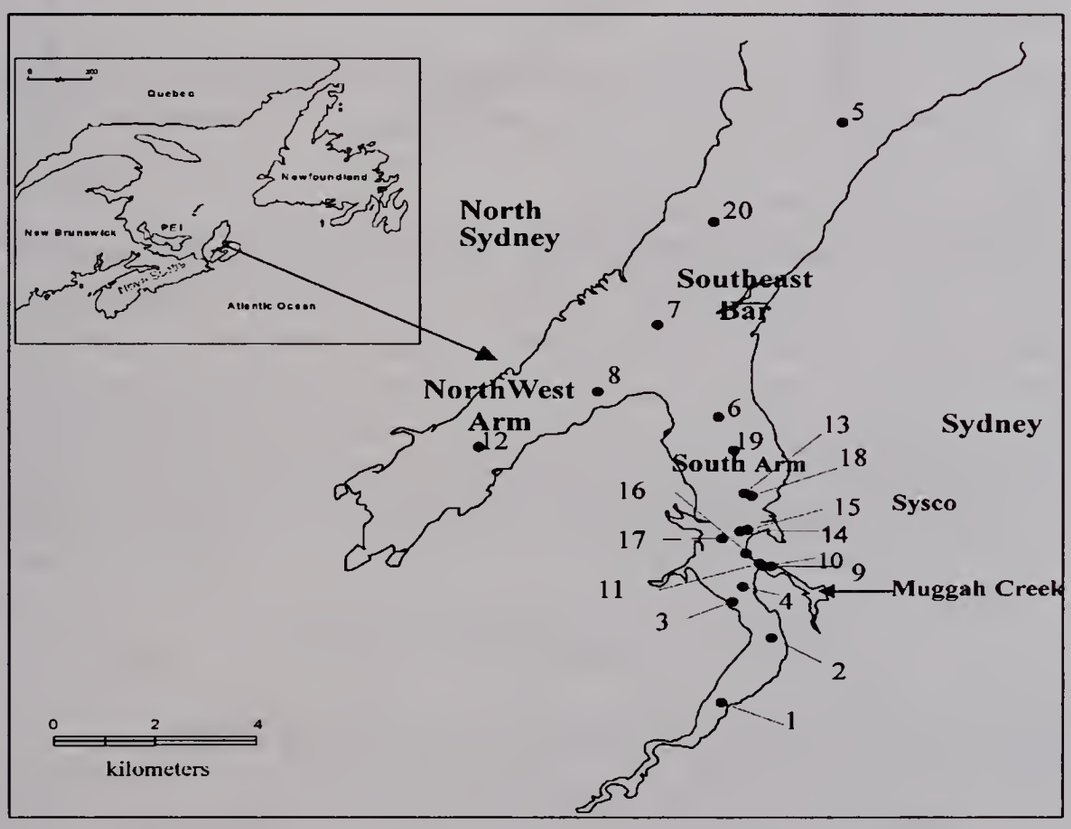

Fig 2 Map of selected sediment sites. Lobsters were collected near Site 16.

ficient material was not obtained, the grab sampler was deployed again until the sample size prerequisite was satisfied by the composite sample. Samples of water, suspended particulate matter and sediments were collected at the same time. The samples were homogenized and sub-sampled.

Market-sized lobsters [519±59 grams (with claws, tail and hepatopancreas weighing 29±4 grams)] five to ten animals per site were collected using standard commercial traps in 1982, 1984, 1991 and 1995 (Table 1).

Table 1 PAH concentrations (ng.kg-1 wet wt. in lobster tomalley).[1]

Chemical Compound	South Arm Sydney Harbour						St. Margarets Bay
	1982	1982	1984	1984	1991	1995	1995
Fluoranthene	15200	12400	4220	5240	4660	3900	330
Pyrene	13100	9150	3180	2910	3310	2700	140
Benz[a]Anthr	32700	18000	762	1150	940	790	47
Chrysene	1030	252	770	1240	1260	1700	140
B[b]Fl	3820	2460	1020	1550	1080	1600	42
B[k]Fl	955	640	502	813	571	798	10
B[a]P	1430	930	711	1260	720	790	23
B[ghi]Pyl	769	479	232	459	200	520	

[1] Abbreviations: Benz[a]Anthr-Benz[a]Anthracene, B[b]Fl-Benzo[b]Fluoranthene, B[k]fl- Benzo[k]Fluoranthene, B[a]P-Benzo[a]Pyrene, B[ghi]pyl-Benzo[ghi]perylene.

St. Margarets Bay

Samples of sediment, water and lobsters were collected in a commercial fishery site near the Head of St. Margarets Bay.

Sample Preparation and Analysis

Sediment samples were prepared according to the Environmental Protection Agency (EPA) method 3540C (1996). Live lobsters were taken to the lab and dissected to remove the digestive gland (hepatopancreas) intact. The digestive glands were prepared according to Uthe and Musial (1986) and King et al. (2003). Early sample extracts (1982 and 1984) were analysed by reverse phase high performance liquid chromatography and in later studies by gas chromatography/mass spectrometry (1991 and 1995).

RESULTS AND DISCUSSION

Contaminant Concentrations in Environmental Media

Samples of biota, sediment, and water were evaluated. Temporal trends (1986-1995) revealed that PAH concentrations in sediments from 24 of 38 stations had decreased since the closure of the coal coking plants (Ernst et al. 1999). More recent studies (1999, July and October 2000) revealed a continuous downward temporal trend (Lee et al. 2002). The sediments contained substantial PAH concentrations as illustrated in Fig 3. PAHs are insoluble in water; therefore most of the water samples gave results in parts-per-billion levels (ppb) and because the amounts were so small, these data are not included in the figure. Lobster results from 1984 to 1995 for Sydney Harbour and 1995 data for St. Margaret Bay (SMB) are presented in Table 1. The PAH concentrations decreased in lobster (1984-1995) and the temporal trends are similar to those reported by Ernst et al. (1999).

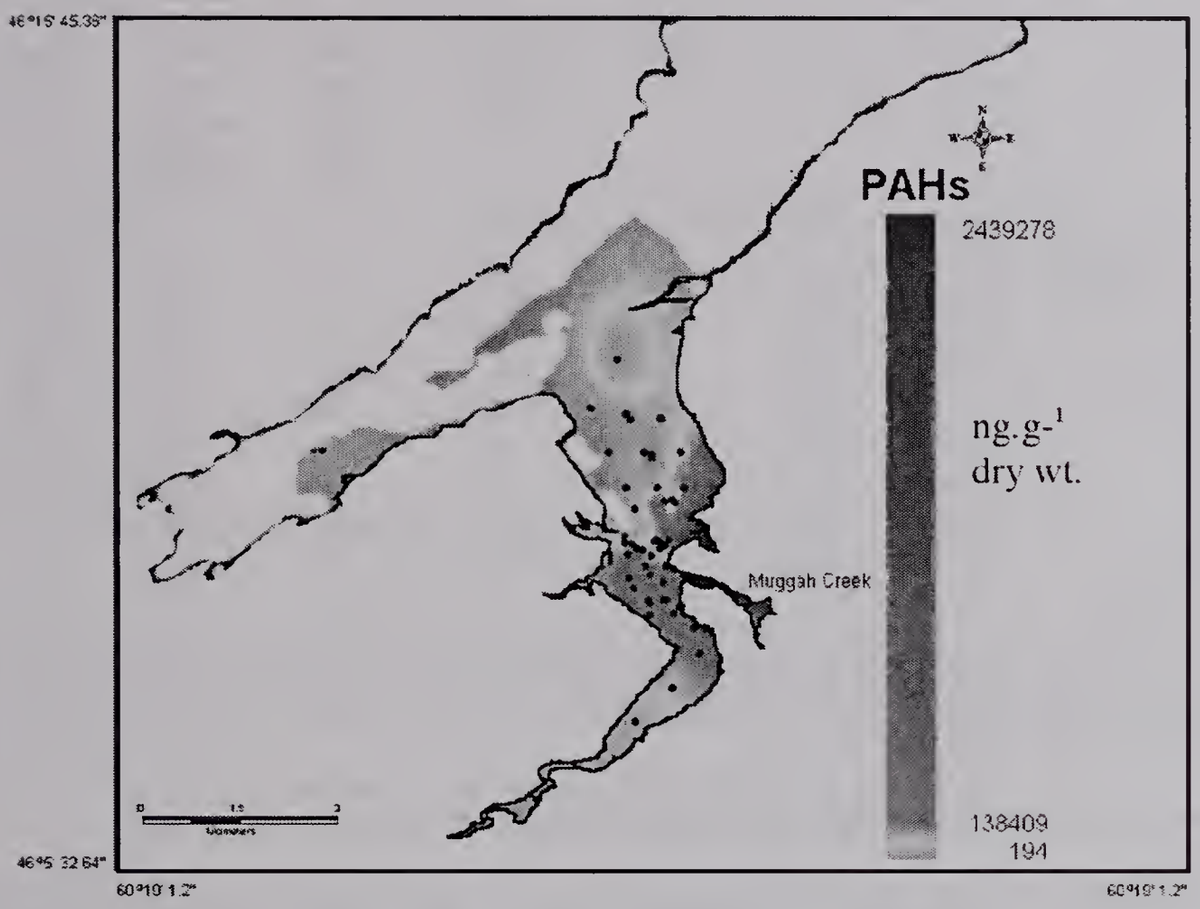

Fig 3 PAHs ($ng \cdot g^{-1}$) distribution in sediment grabs collected in Sydney Harbour from 1999-2001.

Hazard Identification

Screening and Identification of Contaminants of Potential Concern.

Both the Canadian (Canadian Council for Ministers of the Environment 2001) and American (United States Environmental Protection Agency 1999) governments have established marine sediment quality guidelines for 13 individual PAHs. Sediments from the mouth of Muggah Creek (stations 9-11) exceed the Canadian Probable Effects Level (PEL) by 100 to 380 times and American Effects Range-Median (ERM) by 48 to 180 times. In the South Arm sediment concentrations exceeded the PEL by 2.8 to 71 times and the ERM by 1.8 to 34 times (King and Lee 2004). Thus PAHs exceeded both guidelines (King & Lee 2004).

The Canadian standards (maximum acceptable level) of B[a]P toxic equivalency in retail food is 3 $ng.kg^{-1}$ (Health Canada 2007). Digestive glands of lobsters procured from the South Arm of Sydney Harbour exceeded this level considerably (Table 2).

Identification of Potential Recipients

The recipients were Sydney residents: fishers, tourists, and aboriginal people exposed to the contaminated lobster. The subject group addressed in this study was 20+ years of age.

Table 2 Average PAH and TEQ B[a]P concentrations (ng.kg^{-1} wet wt. in lobster tomalley).[1]

Chemical Compound	SA 1982	SA 1984-1985	SMB	Nisbet & Lagoy 1982	SA TEQ B[a]P 1982	SA TEQ B[a]P 84-95	SMB TEQ B[a]P
	AVE	AVE		TEFs			
Fluoranthene	13800	4505	330	0.001	14	4.5	0.3
Pyrene	11125	3025	140	0.001	11	3.0	0.1
Benz[a]Anthr	25350	911	47	0.1	2535	91	4.7
Chrysene	641	1243	140	0.01	6.4	12	1.4
B[b]Fl	3140	1313	42	0.1	314	131	4.2
B[k]Fl	798	671	10	0.1	80	67	1.0
B[a]P	1180	870	23	1.0	1180	870	23
B[ghi]Pyl	624	353		0.01	6.2	3.5	
∑TEQ-B[a]P					4147	1182	35

[1] Abbreviations: SA-South Arm, SMB- St. Margarets Bay, Benz[a]Anthr-Benz[a]Anthracene, B[b]Fl-Benzo[b]Fluoranthene, B[k]fl- Benzo[k]Fluoranthene, B[a]P-Benzo[a]Pyrene, B[ghi]pyl-Benzo[ghi]perylene.

Exposure Pathways (Monitoring Lobster for Contaminants)

Source.

The Tar Ponds located in Sydney Nova Scotia, contain PAHs, PCBs, and heavy metals in appreciable levels (Ernst et al. 1999, Lee 2002).

Environmental Distribution and Exposure Pathways.

The focus was placed on distribution of contaminants to lobsters. The toxic chemicals that were discharged from the coking plants were rich in PAHs. The solubility of PAHs is low in water and decreases with increasing molecular weight. The log K_{ow}s (i.e. octanol/water partition coefficients) ranged from 3.33 to 6.50 (ABB Environmental Services Inc. 1990). PAHs are associated with particulate and dissolved material and tend to be deposited in the sediments. Partition coefficients (from averages for the 1999, July and October 2000 samples) were generated for a number of PAHs and plotted against their log K_{ow}s, which illustrates that the PAHs partitioning between the water and particles, were at equilibrium based on the regression line approaching linearity (Fig 4). The PAHs were widely distributed in the South Arm and the results were consistent with water/sediment partitioning for PAHs from a pyrogenic source.

The bioavailability of B[*a*]P (and other PAHs) is significantly affected by the quality and quantity of dissolved organic matter (Akkanen et al., 2001). Bioavailability of PAHs in sediments is greatly affected by carbon content. Some characteristics that effect binding of hydrophobic organic compounds include aromaticity, hydrophobic acid content, and molecular size (McCarthy et al. 1989, Kukkonen & Oikari 1991, Chin et al. 1997, Haitzer et al. 1999). An increase in any one of the above causes greater binding of organic chemicals. This increased binding causes a reduction in bioavailability (Kukkonen et al. 1990). The strong correlation between total organic

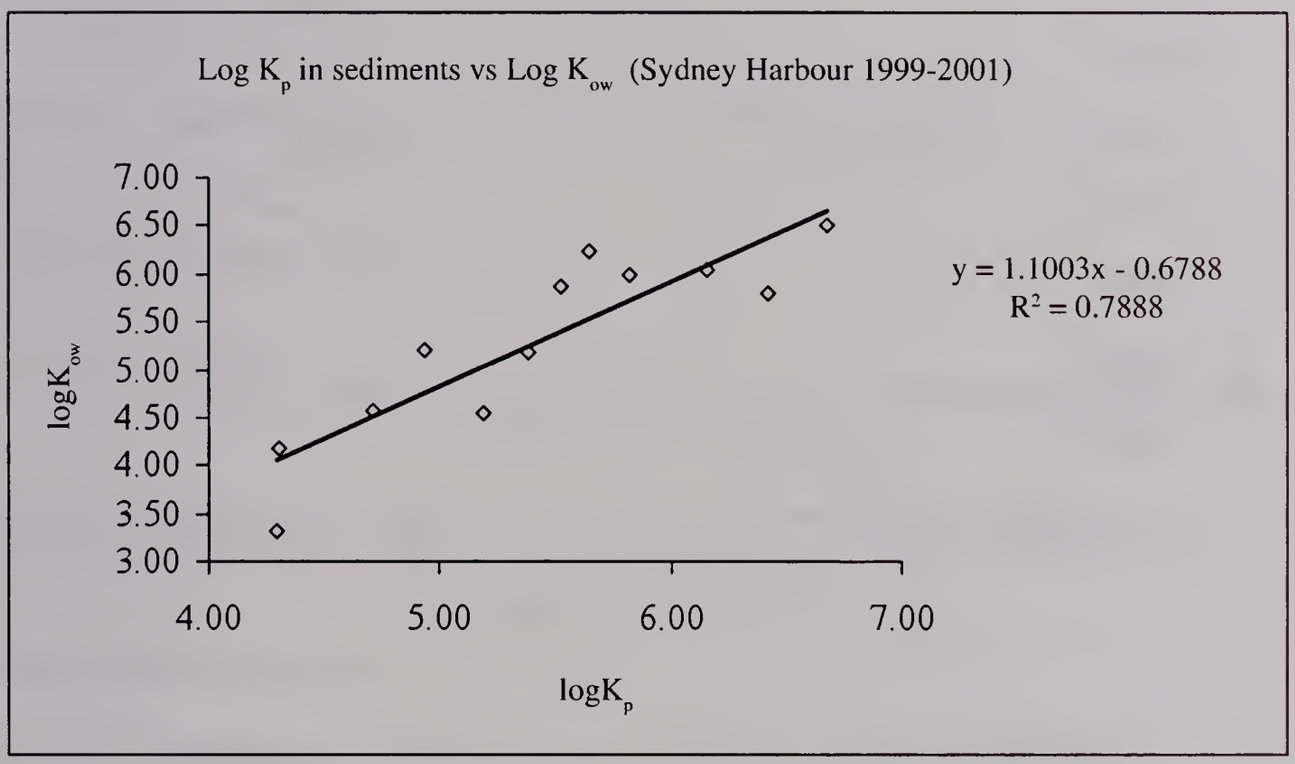

Fig 4 Correlation between the averaged calculated logK_p vs logK_{ow}

carbon (TOC) and PAH concentrations indicates that there are appreciable quantities of >4 ring PAHs in the sediments and the source is most likely pyrogenic (Fig 5). Contaminated sediments have been shown to be bio-available as evidenced by their toxicity to amphipods, marine bacteria and their bioaccumulation in clams, *Macoma balthica* (Lee 2002). Previous studies by Tay et al. (1992) showed that sediments from the Sydney Tar Ponds were toxic to marine organisms. The high molecular wt. PAHs (>4 ring) are persistent and have the potential to bioaccumulate in the tissues of some animals and bio-magnify in the food chain. As a result, there is risk to predators, such as lobsters through the water or the consumption of contaminated prey. This risk could be extended to humans by their consumption of contaminated fish or shellfish from the harbour.

The tomalley (hepatopancreas) was the lobster part examined in this study. In order to estimate how many people eat tomalley, a survey of 100 people at a lobster dinner in 2007 was conducted and determined that 90% of the individuals that consumed lobsters ate both the meat (from claws and tails) and the tomalley.

Exposure Assessment (Estimating Risks to Humans)

Benzo[a]pyrene Toxic Equivalent Factors.

B[a]P is a carcinogen and has been shown to suppress the immune response of mammals (Carlson et al. 2002). B[a]P is a major contributor to the high molecular weight PAH (>4 benzene rings). This compound is particle bound and readily available to be taken up by marine organisms, such as lobsters. B[a]P, once taken up by lobsters and other organisms, undergoes biotransformation in the form of hydroxylation (Stine & Brown

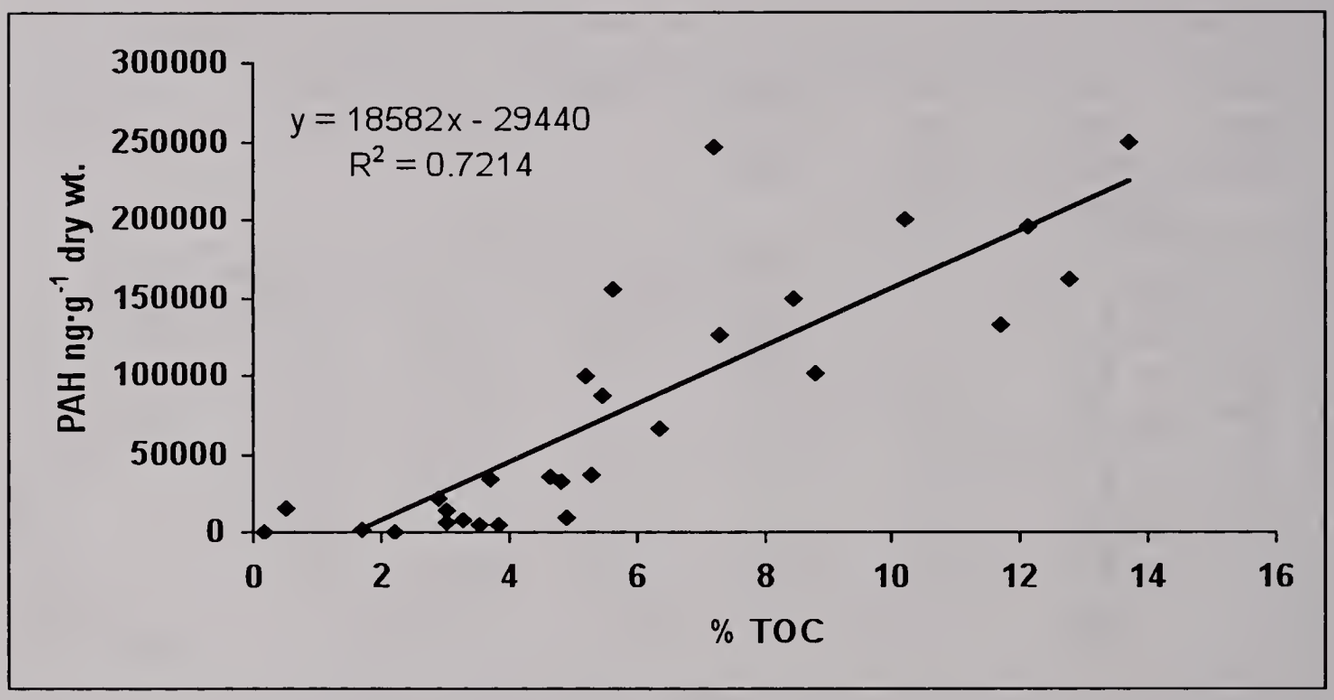

Fig 5 Correlation plot of PAH concentration against Total Organic Carbon

1996). This results in the production of B[a]P-7,8-diol, which can be further epoxidated to form B[a]P-7,8-diol-9,10 epoxide. This compound is even more reactive with DNA than is the parent compound.

Toxicological data for B[a]P is readily available compared to other PAHs. Even though there is inadequate data to assess the risk of individual PAHs, there is sufficient data for several compounds to approximate cancer potencies to B[a]P (Yender et al. 2002). It is important to note that this approach can only be applied to pyrogenic (combustion of fossil fuels, such as coal tar) sources rather than petrogenic sources (petroleum based), because high molecular weight PAHs, such as B[a]P are not present in detectable concentrations in petrogenic sources. Benzo[a]pyrene toxic equivalent (TEQ) concentrations (individual PAH concentrations multiplied by the B[a]P toxic equivalent factor) were calculated for lobster (Table 2).

Equations and Risk Calculations.

Adult Lobster Consumer Exposure Assumptions

Lobster tissue concentration (mg/kg w/w)	TC	TEQ B[a]P (Table 2)
Cancer slope factor (per mg/kg-day)	CSF	0.11
Reference Dose factor (mg/kg-day)	RfD	NV
Consumption rate-daily average (g/day)	CR	6
Relative absorption factor (oral)	RAF	1
Exposure frequency (days/yr)	EF	365
Exposure duration (yr)	ED	50
Body weight (individual average in kg)	BW	70
Conversion Factor (kg/g)	CF	0.001
Averaging time-car. (days)	ATc	25550
Averaging Time-noncar. (days)	ATnc	18250

Intake Calculations.

$$\text{Intake} = \frac{TC \times CR \times EF \times ED \times RAF \times CF}{BW \times AT}$$

Before Fishery Closure

$$\text{Sydney (intake)} = \frac{(4.147\text{mg.kg-1}) \times (6\text{g/day}) \times (365\text{ days/yr}) \times (50\text{ yr}) \times (1) \times (0.001\text{kg/g})}{(70\text{kg}) \times (25550\text{days})}$$

$$\text{Intake (carcinogen B[a]P)} = \frac{(454.1\text{mg})}{(1788500\text{ kg/day})} = 2.54 \times 10^{-4}\text{mg/kg/day}$$

After Fishery Closure

$$\text{Sydney (intake)} = \frac{(1.182\text{mg.kg-1}) \times (6\text{g/day}) \times (365\text{ days/yr}) \times (50\text{ yr}) \times (1) \times (0.001\text{kg/g})}{(70\text{kg}) \times (25550\text{days})}$$

$$\text{Intake (carcinogen B[a]P)} = \frac{(129.4\text{mg})}{(1788500\text{ kg/day})} = 7.24 \times 10^{-5}\text{mg/kg/day}$$

$$\text{SMB (intake)} = \frac{(0.035\text{ mg.kg-1}) \times (6\text{g/day}) \times (365\text{ days/yr}) \times (50\text{ yr}) \times (1) \times (0.001\text{kg/g})}{(70\text{kg}) \times (25550\text{days})}$$

$$\text{Intake (carcinogen B[a]P)} = \frac{(3.83\text{ mg})}{(1788500\text{ kg/day})} = 2.14 \times 10^{-6}\text{mg/kg/day}$$

Risk Estimate.

Risk = intake (Carc) x cancer slope factor

Risk (Sydney before closure) = 0.000254mg/kg/day x 0.11 per mg/kg/day) $= 2.79 \times 10^{-5}$

Risk (Sydney after closure) = 0.0000724mg/kg/day x 0.11 per mg/kg/day) $= 7.96 \times 10^{-6}$

Risk (SMB) = 0.0000021 mg/kg/day x 0.11 per mg/kg/day) = 2.31×10^{-7}

Hazard Estimate.

Hazard=intake (non-carc)/reference dose factor

RDF are present for 3 compounds only, benzo[ghi]perylene (B[ghi]Pyl), fluoranthene (Fl), and pyrene (P). A total hazard estimate will be calculated summing the estimated hazard from these compounds.

Sydney Site (Before Closure)

$$\text{Hazard (B[ghi]Pyl)} = \frac{0.000254\text{mg/kg/day}}{0.004\text{ mg/kg/day}} = 0.064$$

$$\text{Hazard (Fl)} = \frac{0.000254\text{mg/kg/day}}{0.04\text{ mg/kg/day}} = 0.0064$$

$$\text{Hazard (P)} = \frac{0.000254\text{mg/kg/day}}{0.03\text{ mg/kg/day}} = 0.0085$$

Total Hazar d = 0.079

Sydney Site (After Closure)

$$\text{Hazard (B[ghi]Pyl)} = \frac{0.0000724\text{mg/kg/day}}{0.004\text{ mg/kg/day}} = 0.018$$

$$\text{Hazard (Fl)} = \frac{0.0000724\text{mg/kg/day}}{0.04\text{ mg/kg/day}} = 0.0018$$

$$\text{Hazard (P)} = \frac{0.0000724\text{mg/kg/day}}{0.03\text{ mg/kg/day}} = 0.0024$$

Total Hazard = 0.022

St. Margarets Bay Site

$$\text{Hazard (B[ghi]Pyl)} = \frac{0.0000021\text{mg/kg/day}}{0.004\text{ mg/kg/day}} = 0.00053$$

$$\text{Hazard (Fl)} = \frac{0.0000021\text{mg/kg/day}}{0.04\text{ mg/kg/day}} = 0.000053$$

$$\text{Hazard (P)} = \frac{0.0000021\text{mg/kg/day}}{0.03\text{ mg/kg/day}} = 0.00007$$

Total Hazard = 0.00065

Risk Characterization

Integrating Hazard and Exposure Data.

The current risk to humans was estimated based on consumption of lobster contaminated with PAHs using the TEQ B[a]P concentrations to estimate the risk. Average adults that consume lobster are estimated to do so twice annually while heavy consumers eat lobsters about 6 to 10 times annually (Conestoga-Rovers & Associates 2003). A serving was estimated to be ¼ of a kilogram; therefore heavy consumers eat about 1.4 to 2.3 kg annually. The result was 6 g/day/yr for a person considered to be a heavy eater. Taking into consideration the consumer exposure and using the intake and risk estimate equations, a cancer risk was determined for adults (20+ years) consuming lobster procured from the South Arm of Sydney Harbour and St. Margarets Bay. A total cancer risk estimate of 7.96×10^{-6} and 2.31×10^{-7} (see risk estimate section for calculations) for lifetime consumers of Sydney and St. Margarets Bay lobsters respectively were calculated. The provincial regulatory guidelines accept an incremental lifetime cancer risk of 1×10^{-5}. Thus the values calculated in this study were well below the acceptable guidelines.

Prior to the closure of the Coke Ovens, the estimated incremental lifetime cancer risk was 2.79×10^{-5}, approximately 3 times higher than the provincial acceptable levels, hence the closure of the South Arm to commercial fishing. The non-cancer hazard (source of potential damage or adverse health effects from non-carcinogenic PAHs) calculated in all cases, is well below the acceptable target hazard level of 0.2. The data calculated in this study was comparable to estimates calculated by Conestoga-Rovers & Associates (2003).

Uncertainty in the Approach.

There are several areas of uncertainty to consider. The analyses are focused on the use of previous data sets (1985-1995). The regulatory guideline for acceptable cancer risk varies from province to province in Canada (i.e. BC, Alberta and the Atlantic provinces accept an incremental lifetime cancer risk of 1×10^{-5}, while Ontario uses 1×10^{-6}). Provincial statistical approaches for exposure calculations also vary; some use maximum concentrations, some use average concentrations, others use 95% upper confidence limit of the mean and yet others use 90 or 95% values of the available data (Health Canada 2004). There are also varying toxic equivalent factors for B[*a*]P (Yender et al. 2002). However, this does not appear to affect the results in this study significantly. The average concentrations used in this study were based on data collected from 1984 to 1995. As the variance in the data set was small after the closure of the fishery, using averages is adequate for this data set. There would have to be a significant change in concentration (at least 10 fold) in order to cause a significant change (10 fold) in the risk estimates.

Another uncertainty involves the assumption that PAHs are the primary stressor affecting benthos. Other chemicals, such as heavy metals, PCBs,

and alkyalted PAHs are present in detectable concentrations and the accumulated effects may increase the cancer risk and non-cancer hazard estimates from consuming lobster from Sydney Harbour.

CONCLUSIONS

The sediments and lobster PAH concentrations decreased after the closure of the coal coking plants. This decreasing temporal trend in environmental compartments is consistent with the computed carcinogenic risk from PAHs, which according to the NS provincial regulatory guidelines had decreased from unacceptable in 1982 to acceptable in 1995. TEQ B[a]P were adequate for determining the overall PAH risk, as there is no data to access the risks for all the individual PAHs in this study. The non-cancer hazards calculated in all cases were below the acceptable target hazard level. The clean St. Margarets Bay control site was a suitable reference site for background levels of PAHs in the province of Nova Scotia. Considerations concerning the fisheries in the South Arm would require a more comprehensive risk assessment in order to address the more recent effects from other contaminants and perhaps extend future studies to other commercial species of fish to evaluate the safety of annual consumption of fish from Sydney Harbour.

REFERENCES

ABB Environmental Services Inc (1990) Compiling of data on the composition, physical characteristics and water solubility of fuel products. Prepared for: Massachusetts Department of Environmental Protection. Job No. 6042-04, p 1-3

Akkanen J, Penttinen S, Haitzer M, and **KukkonenVK** (2001) Bioavailability of atrazine, pyrene and benzo[a]pyrene in European river waters. Chemosphere 45:453-462

Carlson EA, Li Y, Zelikoff JT (2002) Exposure of Japanese Medaka (*Oryzias latipes*) to benzo[a]pyrene suppresses immune function and host to resist against bacterial challenge. Aquatic Toxicolog 56:289-301

Canadian Council of Ministers of the Environment (2001) Sediment Quality Guidelines. http://www.ec.gc.ca/ceqg-rcqe/English/Ceqg/Sediment/default.cfm [accessed 8 July 2008]

Canadian Environmental Assessment Agency. (2005) Sydney Tar Ponds and Coke Ovens Site Remediation Project. http://www.ceaa-acee.gc.ca/050/Viewer_e.cfm?SrchPg=1&CEAR_ID=10749 [accessed 8 July 2008]

Chin, YP, Aiken GR, Danielsen KM (1997) Binding of pyrene to aquatic and commercial humic substances: The role of molecular weight and aromaticity. Environ Sci Technol 31:1630-1635

Conestoga-Rovers & Associates (2003) Estimation of the impact of current loading of PAHs from Muggah Creek to Sydney Harbour. Muggah Creek Remediation Project Ref. No. 14458-08 (42)

Guernsey, JR, Dewar R, Weerasinghe S, Kirkland S, Veugelers PJ (2000) Incidence of cancer in Sydney and Cape Breton County, Nova Scotia 1979-1997. Can J Public Health 91:285-292

EPA (Environmental Protection Agency) (1996) Method 3540C Soxhlet Extraction. http://www.scribd.com/doc/1673016/Environmental-Protection-Agency-3540c [accessed 30 August 2008]

Ernst B, Pitcher D, Matthews S, Julien G (1999) Concentrations and distribution of polycyclic aromatic hydrocarbons (PAHs), PCBs and metals in sediments, mussels (*Mytilus edulis* and *Modiolus modiolus*) and lobsters (*Homarus americanus*) from Sydney Harbour, Nova Scotia. Environment Canada (Atlantic Region), Surveillance Report EPS-5-AR-99-7

Haitzer M, Abbt-Braun G, Traunspurger W, Steinberg CEW (1999) Effect of humic substances on the bioconcentration of polycyclic aromatic hydrocarbons: Correlations with spectroscopic and chemical properties of humic substances. Environ Toxicol Chem 18:2782-2788

Health Canada (2004) Contaminated Sites Program. Federal Contaminated Site Risk Assessment in Canada. Part I: Guidance on human health preliminary quantitative risk assessment (PQRA). Cat H46-2/04-367E. ISBN 0-662-38244-7.

Health Canada (2007) Canadian standards (maximum limits) for various chemicals in foods. http://www.hc-sc.gc.ca/fn-an/securit/chem-chim/contaminants-guidelines-directives-eng.php#guidelines [accessed 20 August 2008]

King TL, Chou CL (2003) Anthropogenic organic contaminants in American lobster (*Homarus americanus*) procured from harbours, bays, and inlets of eastern Canada. Can Tech Rep Fish Aquat Sci 2456: v-24

King TL, Lee K (2004) Assessment of sediment quality based on toxic equivalent benzo[a]pyrene concentrations. In: Proceedings of the 27th Arctic and Marine Oilspill Program (AMOP), Edmonton, Alberta, Canada, June 8-10, 2004. Environmental Science and Technology Division, Environment Canada, Ottawa, Ontario, Canada. p 793-806

Kukkonen J, McCarty JF, Oikari A (1999) Effects of XAD-8 fractions of dissolved organic carbon on the sorption and bioavailability of organic micropollutants. Arch Environ Contam Toxicol 19:551-557

Kukkonen J, Oikari A (1991) Bioavailability of organic pollutants in boreal waters with varying levels of dissolved organic material. Water Res 25:455-463

Lee K (2002) Environmental effects and remediation of contaminants in Sydney Harbour, Nova Scotia, Section 4: Levels of sediment toxicity within Sydney Harbour and its approaches, Final report to Health Canada for Toxic Substances Research Initiative (TSRI) Project #93

McCarthy JF, Roberson LE, Burris LW (1989) Association of benzo[a]pyrene with dissolved organic matter: Prediction of K_{dom} from structural and chemical properties of the organic matter. Chemosphere 19:1911-1920

Nisbet ICT, LaGoy PKN (1992) Toxic equivalency factors (TEFs) for polycyclic aromatic hydrocarbons (PAHs). Regul Toxicol Pharmacol 16:290-300

Prouse N (1994) Ranking harbours in the marine provinces of Canada for potential to contaminate American lobster (*Homarus americanus*) with polycyclic aromatic hydrocarbons. Can Tech Rep Fish Aquat Sci 1960: v-50

Tay Kok-Leng, Doe KG, Wade SJ, Vaughan DA, Berrigan RE, Moore MJ (1992) Sediment bioassessment in Halifax Harbour. Environ Toxicol Chem 11:1567-1581

Uthe JF, Musial CJ (1986) Polycyclic aromatic hydrocarbon contamination of American lobster, *Homarus americanus*, in the proximity of a coal-coking plant. Bull Environ Contam Toxicol 37:730-738

United States Environmental Protection Agency (1999) Sediment quality guidelines. http://www.epa.gov/waterscience/cs/library/guidelines.htm#epa [accessed 8 July 2008]

Yender R, Michel J, Lord C (2002) Managing seafood safety after an oil spill. Seattle: Hazardous Materials Response Division, Office of Response and Restoration, National Oceanic and Atmospheric Administration

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THE NOVA SCOTIAN INSTITUTE OF SCIENCE STUDENT SCIENCE AWARDS 2007

Purpose

To provide an opportunity for students to have their work recognized by a scientific society and to have it considered for publication in a peer-reviewed scientific journal.

Eligibility

The competition is open to any student currently enrolled in a degree program at a recognized educational institution.

Categories and prizes

Undergraduate student

Three broad categories for competition:

Environmental Sciences	e.g. terrestrial ecology, marine biology atmospheric sciences, earth sciences etc.
Life Sciences	e.g. animal and plant cell biology, medical sciences, biochemistry, physiology etc.
Physical Sciences	e.g. physics, chemistry, engineering, mathematics, computer science etc.

Three undergraduate prizes are available in each of these three categories:

1st prize	$200 plus one year's membership to NSIS
2nd prize	$100 plus one year's membership to NSIS
3rd prize	one year's membership to NSIS

Graduate Student

Any discipline
Single prize of $500 plus one year's membership to NSIS

Scientific Writing

For an article written by a student in a non-scientific discipline
Subject must be relevant to science in Nova Scotia
Single prize of $200 plus one year's membership to NSIS

STUDENT SCIENCE AWARDS 2007

The Scientific Writing Prize was awarded to:
Jason Loxton
Department of Earth Sciences
Dalhousie University
for
"Pseudoscience and the paranormal:
Obligations and opportunities for scientists and science educators"

The Scientific Writing Honourable Mention was awarded to:
Benjamin H. Rotstein
Departments of Chemistry & Contemporary Studies
University of King's College and Dalhousie University
for
"James Hansen: Science and society in a greenhouse"

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2007 Scientific Writing Award

PSEUDOSCIENCE AND THE PARANORMAL: OBLIGATIONS AND OPPORTUNITIES FOR SCIENTISTS AND SCIENCE EDUCATORS

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Despite increasing reliance on science and technology in everyday life, public surveys conducted over the past decade have shown consistently low levels of general science literacy, both factual and conceptual, and correspondingly high levels of belief in pseudoscience and the paranormal. Scientists and science educators have largely failed to effectively counter these beliefs through traditional education and outreach initiatives, suggesting a new approach is in order. In the academic setting, general science instruction shows little effect on pseudoscientific belief, but trial projects show that pedagogical approaches that directly engage these beliefs are both popular with students and effective at increasing skepticism.

Malgré une dépendance accrue de la vie quotidienne sur les sciences et la technologie, les sondages publics réalisés au cours de la dernière décennie ont constamment reflété un faible niveau de littéracie, tant factuelle que conceptuelle, en sciences générales et un haut niveau correspondant de croyance dans les pseudosciences et le paranormal. Les scientifiques et les éducateurs en sciences ont largement échoué dans leurs tentatives de contrer ces croyances par des initiatives de vulgarisation et d'éducation traditionnelle, ce qui permet de croire qu'une nouvelle approche est de mise. En milieu scolaire ou universitaire, l'apprentissage des sciences générales se révèle sans grand effet sur les croyances pseudoscientifiques, mais des projets pilotes démontrent que les approches pédagogiques qui prennent directement à partie ces croyances ont la faveur des écoliers et étudiants, et parviennent à accroître le scepticisme.

MONTEL WILLIAMS: And he could be found near there?
SYLVIA BROWNE: He's near the boulders.
PAM HORNBECK: Is he still with us?
SYLVIA BROWNE: No.

January 12, 2007 a miracle took place, or maybe two miracles if you're counting. That stormy Friday, 15-year-old Shawn Hornbeck, missing since October 6, 2002, and 13-year-old Ben Ownby were discovered in the custody of Michael J. Devlin, a 41-year-old pizzeria manager in Kirkwood, Missouri. As the news spread, the state and much of the country—glued to the investigation since the younger Ben was abducted four days earlier—let out a collective sigh of relief. They hadn't expected this. These things don't usually work out well, and everyone realized the odds of finding Ben

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alive were low. Those for Shawn were astronomical, especially since he had been previously pronounced dead. Twice.

The story of Shawn's premature declaration of "passage" is a sordid one. In their desperate search for answers, Shawn's parents had turned to two celebrity "psychics", Sylvia Browne and James Van Praagh, both of whom confirmed on international television their worst fears: Shawn had been murdered (Boyle 2007).

With the recovery of Shawn Hornbeck alive, these readings were revealed as failures in every conceivable detail, failures which had wasted police resources and caused unimaginable anguish for the Hornbecks. The media response was swift and violent. In the days following, skeptics were rounded up for interviews and exposé segments on psychic charlatans aired. And then, a few weeks later, it all blew over, and the psychics again began appearing on talk shows.

The immovable presence of mediums and psychics is just one manifestation of the popular media's systematic uncritical promotion of fringe claims. The market mechanism here is obvious: the strange, the bizarre, and the just-might-be-true sell. To cite one example, 15 million Americans—nearly one in twenty—tuned in to watch Fox Television's *Conspiracy Theory: Did We Land on the Moon?* It is hard for networks to resist this kind of cash cow. What is less clear is why the public is so interested.

Defining the issue: What is 'Pseudoscience'? What is 'Science'?

Whole subfields of philosophy, history, and sociology exist to debate this question, and it won't be resolved here. But, useful working definitions can be easily produced. Michael Shermer (1997), author of *Why People Believe Weird Things*, defined 'science' as "a set of methods designed to describe and interpret observed and inferred phenomena, past or present, and aimed at building and testing a body of knowledge open to rejection or confirmation" and 'pseudoscience' as "claims presented so they appear [to be] scientific even though they lack supporting evidence and plausibility".

The philosopher Michael Martin (1994) offered similar criteria for demarcation, emphasising the differences between superficial and depth qualities of science: pseudoscience is linked to science by surface similarities, such as its tendency to develop a technical language, require specialized training, reference evidence, etc. However, it differs at depth by a reluctance to subject its claims to proper test, the frequent invocation of *ad hoc* explanations when its claims fail tests, and a tendency to isolate itself from other scientific disciplines.

The scope of the problem

About 75 percent of Americans hold at least one of ten common pseudoscientific beliefs, with 22 percent believing in five or more (Moore 2005). Particularly popular are telepathy, ghosts, haunted houses, and precognition, all of which are accepted as true by 30 to 40 percent of respondents. As for most of the topics discussed in this paper, data are limited or absent for Canada, but Canadians and Americans tend to share similarly high

levels of belief in pseudoscience and the paranormal (Lindeman & Aarnio 2006)—for example, 40 percent of British Columbians believe in ghosts (Leung 2006)—so the American data can stand as a reasonable proxy.

Scientists, science educators, and science students tend to be somewhat less credulous than the general public, but even within the science community, pseudoscientific belief is remarkably strong. One survey of high school biology teachers found that 34 percent believed in psychic powers, 22 percent in ghosts, and 18 percent in a supernatural explanation for the Bermuda Triangle (Eve & Dunn 1989). A more recent qualitative study of Australian and British working scientists and science professors found widespread belief in alien landings, the healing powers of crystals, and the existence of ghosts, as well as strong individual support for nearly all major categories of the paranormal, e.g., Ouija boards, water divining, etc. (Coll & Taylor 2004).

Finally, although science students have been shown in several studies to manifest lower levels of paranormal belief (e.g., Aarnio & Lindeman 2005), the reduction is only marginal, with field of study statistically less predictive of level of belief than numerous other variables (such as sex).

What's the harm in a little pseudoscience?

This question can and has been treated at book length, e.g. James Randi's *Flim-Flam!* (1982), but two particularly widespread examples—"psychic" phenomena and alternative medicine—can serve to illustrate the potential for harm, both direct and indirect.

No figures are kept on the amount of money spent annually on psychic consultations. Fees can range from a few dollars to several thousand (bids for pet psychic readings start at $50 US on eBay), but the total is likely in the billions. As an indication of scale, in 2002 Florida-based ARS, Inc. (the company behind prominent telephone psychic "Miss Cleo") agreed to forgive nearly $600 US million in outstanding bills following action by the Federal Trade Commission and several states into deceptive marketing practices (Christopher 2003).

Some psychics also profit by extortion, demanding payment for protection against supernatural threats. During 2005, the Australian Department of Consumer and Employment Protection reported 1,326 individual scams involving psychics (DOCEP 2005). In one example, an 82-year-old pensioner was convinced to pay $40,000 AU for protection from evil forces. Similarly, recent research commissioned by the UK's Office of Fair Trading showed more than 170,000 consumers fall victim to clairvoyant mail scams every year, losing around £40 million (Moon 2007).

Regardless of monetary costs, many skeptics object primarily to what they see as intellectual and emotional fraud. For example, although psychics who claim to contact the dead may provide some immediate relief to the bereaved, the dishonest, manipulative use of stock magician's tricks to deliver that result is ethically dubious. Additionally, this temporary fix can spawn future problems by, as reformed spiritualist conman M. Lamar Keene

(1997) explains, "hinder[ing] him or her in developing the inner resources to face life realistically."

Complementary and alternative medicine (CAM) presents another growing area of concern. The term is a grab bag of health modalities that embraces literally everything from alchemy and "psychic surgery" to meditation and a healthy diet. The risks and/or benefits associated with their use vary accordingly.

The majority of CAM therapies are physically benign (and ineffective); however, their cost and troubled relationship with conventional medicine raise thorny ethical and patient welfare issues. Many herbs do contain active ingredients, but often these herbal drugs are marketed with little or no standardization of dosage. Potential interactions with other common drugs or impact on existing medical conditions are also frequently unknown and/or not noted on product labels.

CAM treatments are used by up to 73 percent of cancer patients (Neuhouser et al. 2001), and the potential for dangerous interactions with chemotherapeutic drugs is well documented (Meijerman et al. 2006). Similarly, Lee et al. (2006) recorded elevated incidence of post-operative events in surgical patients who had previously taken prescribed traditional Chinese herbal medicines. St John's Wort, an herb widely used to treat depression, has been discovered to interfere dangerously with AIDS medications (Henney 2000). Beta-carotene, a popular CAM treatment for lung cancer, has, ironically, been shown to increase rates of the disease, especially among smokers (Goodman et al. 2004).

Delay or rejection of scientifically tested medical interventions is another area of concern. Davis et al. (2006) found that patients with head and neck cancer that used alternative medicine significantly delayed seeking conventional treatment. Although most North American patients with serious illnesses such as cancer use CAM therapies as adjuncts to regular treatment (Maddalena et al. 2006), some do not. Adams et al. (2002) relate the case of a patient who chose to treat her cervical cancer with Reiki (an "energy" therapy where the practitioner waves his or her hands over a patient's body), instead of the recommended surgery. And, in 2000, a jury awarded damages against a New York physician—for the second time in three years—following the death of a patient whose cancer had been treated with a regimen of vitamins and coffee enemas (Radford 2000).

Despite scant evidence of efficacy, spending on CAM therapies is immense. The online industry hocking alternative cancer "cures" alone has become so large—and profitable—that in March, 2008, the Canadian Competition Bureau launched a special program, Project False Hope, to deal with it. Up-to-date figures do not exist, but out-of-pocket expenses in 1997 for alternative therapies and books were estimated at over $34.4 US billion in the United States (Eisenberg 1998) and $3.8 billion in Canada (Ramsay et al. 1999). Today's figures are likely much higher, given the steady rise in popularity of these treatments.

A deeper concern

The emotional, financial, and physical consequences of some pseudoscientific beliefs are troubling, but they are symptomatic of a more worrying civic issue. Most pseudoscientific beliefs are not just unsupported by evidence, they are in direct *conflict* with large bodies of well-established data and longstanding theory. That so many people are unable to differentiate real science from pseudoscience exposes a profound and shockingly widespread ignorance of both basic scientific facts and the nature of the scientific method(s). This ignorance limits the appreciation of nature, increases vulnerability to consumer fraud, and—most importantly—restricts participation in many of the most pressing contemporary policy debates, e.g., Climate Change, effectively disenfranchising a large portion of the population (Maienschein 1999).

Ignorance of what science does, ignorance of what science says

Data for Canada are lacking, but surveys of general science knowledge amongst adult Europeans and Americans show depressingly low levels of scientific literacy. Only 20 percent of US adults meet minimum requirements for scientific literacy (Miller 2004). For example, only 50 percent recognize that the Earth rotates around the Sun once a year. Twenty percent believe that the Sun rotates around the Earth (NSB 2000). Depressingly, these numbers have remained fixed for the last decade.

The average North American also has no clear idea of how science *works*. In a 2004 National Science Foundation survey, only 23 percent of respondents were able to articulate what it meant to study something scientifically, and only 43 percent could identify that an experiment with a control is superior to one without (NSB 2006).

Ignorance of basic science concepts is not limited to the public at large. A survey of US judges found that just 5 percent demonstrated a clear understanding of falsifiability and only 4 percent a clear understanding of error rate. This is despite their being charged as gatekeepers of expert testimony and scientific evidence (Gatowski 2001). Science students do little better. In a study of University of Tennessee science majors enrolled in a second year biology course, not one basic science concept question (e.g., "Science produces tentative conclusions: true or false?") was answered correctly even 50 percent of the time (Johnson & Pigliucci 2004).

Sourcing the problem

Despite these statistics, the average North American is not anti-science. In fact, both Canadians and Americans have very favourable opinions of scientists' intentions and of the benefit of science to their lives (CBS 2005). They also profess a strong interest in scientific topics. A 2001 study found that 45 percent of Americans profess to be "very interested in science and technology," compared with only 30 percent of Europeans (NSB 2006).

Overall, fully 90 percent of Americans claim to be at least moderately interested in science, a statistic that is at least partially born out in practice. According to a study by the European Commission, Americans are twice

as likely as Europeans to go to science and technology museums, and are considerably more likely to go to zoos and aquariums than their European and Asian counterparts (NSB 2006). Given the persistent ignorance of science described above, this seems a paradox.

The astronomer and science popularizer Carl Sagan (1997) explored this conundrum in his book, *The Demon-Haunted World*, and offered an explanation by way of an anecdote: One day his taxi driver, having recognized him as the host of the popular science television series *Cosmos*, began to enthusiastically prod him for information on a number of "scientific" topics of personal interest. But, instead of real science, each question was invariably about some pseudoscientific claim, and each time Sagan had to disappoint him by explaining the reasons why the claim was unlikely to be true. With each answer the driver became more depressed, as Sagan took a little more wonder out of his world.

Sagan uses this story to illustrate what he saw as the double failure of scientists and science educators. First, they failed to ensure their voices stood out against the chorus in favour of the pseudoscientific. And second, and perhaps more importantly, scientists failed to offer an equally interesting alternative. The taxi driver "had a natural appetite for the wonders of the universe. He wanted to know about science. It's just that all the science had gotten filtered out before it reached him." The moral: pseudoscientific topics like ESP and alien abduction are popular precisely because they are exciting and widely available; genuine science, if it is to capture the public's attention, has to learn to compete on these fronts."

A failure to engage

There is wisdom in this argument. Americans, like their international counterparts, express both strong interest in science and dissatisfaction with their current level of knowledge. In the 2004 NSF survey, 69 percent of Americans expressed interest in scientific discoveries, but only 15 percent considered themselves "well-informed" on scientific topics (NSB 2006). These figures suggest an immense opportunity, one that scientists have thus far failed to capitalize on.

This is at least partially, as Sagan (1997) suggests, for lack of effort. A 2001 survey of US scientists found that 42 percent engaged in no public outreach at all, and only 12 and 20 percent engaged in political and media outreach, respectively. The number one reason given, at 76 percent, was insufficient time, but 28 percent also answered that they did not want to, and 17 percent that they did not care (Research!America/Sigma Xi 2001).

Sagan's second prediction is also backed up by recent research. Concerned with public apathy towards science, in 1998 NASA's Space Sciences Laboratory commissioned a blue ribbon panel to evaluate current best practice in science education. Their report criticized many traditional notions about the nature and goals of science communication. In particular, it stressed the gap between the information scientists want to disseminate, and the information the public wants to know (Borchelt 2001). This is a key detail:

the public is interested in the anomalous and the sublime, but scientists have shied away from their coverage, leaving these areas to sensationalistic and/or non-scientific treatments.

A formula for success

Carl Sagan famously applied his own advice in his television series *Cosmos: A Personal Journey.* Airing in 1980, this 13-part science series dealt with topics as diverse and complex as the evolution, structure, and age of the universe; the historical origins and philosophy of science; and the environmental consequences of nuclear war. Despite this, *Cosmos* was a runaway success, winning a Peabody Award and garnering a viewership of over 600 million people world wide.

The phenomenal success of the 2006 BBC series *Planet Earth* (broadcast in over 130 countries) demonstrates that the success of *Cosmos* was not anomalous—popular science can compete with not only pseudoscience, but drama and comedy for a share of the entertainment market. Both of these series succeeded by trading in awe, capturing the audience's attention through the grandeur of nature, and using this as a platform from which to engage in basic science instruction.

The explosive popularity of the Discovery Channel's *MythBusters* demonstrates that in addition to scientific fact, scientific investigative techniques themselves can be popularized. *MythBusters* employs an experimental approach to testing controversial or fringe claims. Episode topics—mostly urban myths—come from audience suggestions and run from the absurd (Can mirrors be used to make a death ray? Can a ninja deflect a bullet with his hand?) to the almost practical (Can running in a zig-zag line save you from a Crocodile? How do you escape from a sinking car?).

Although light-hearted, the show provides a compulsively watchable—and frequently pyrotechnic—illustration of the nature of experimental design and, more importantly, the importance of fact-checking claims. Explaining the design of each test also usually requires a crash course in mechanics or chemistry, providing almost unconscious instruction in often complicated material.

This format has also been used by the illustrated magazine *Jr. Skeptic*, which critically examines claims of the paranormal as a means of teaching children general critical thinking and science concepts. A similar approach can be adapted to the classroom.

The effectiveness of imaginative pedagogy

Frustrated with the resiliency of pseudoscience, even amongst science students, several educators have designed courses that directly target these beliefs. Morier and Keeports (1994) describe the results of one such course: over two years, students consistently showed a substantial drop in belief in pseudoscience relative to a control class. Reductions in belief were also recorded by Wesp and Montgomery (1998) for their course, *Experimental Investigation of the Paranormal*, as well as a significant improvement in students' ability to critically read scientific literature. Dougherty (2004),

Gray (1984), Woods (1984), and Martin (1994) all also recorded positive outcomes for similarly themed courses.

All of these courses taught general nature of science concepts (theory development, hypothesis testing, probability, nature of evidence, logic, etc.) using specific paranormal examples. This approach allowed students to apply conceptual principles to claims and to assess evidence, rather than simply being told what was and was not true. Most of the courses featured an experimental or demonstrative component. Several courses brought in professional mentalists to illustrate techniques by which magicians appear psychic, and one incorporated a controlled test of a professional dowser.

Morier and Keeports (1994) credit this active engagement of claims with providing more consistent changes in belief than other courses that teach general critical thinking. In addition, taking a lesson from Sagan's (1997) taxi driver, learning was aided by using material – the paranormal – that students found naturally interesting, adding a little excitement to a potentially dry subject. In each of three semesters it was offered, *Pseudoscience and Psychology* student evaluations averaged above 8.5 on a 9 point scale for satisfaction with learning outcomes (Lilienfeld et al. 2001). High scores were also recorded by the other instructors noted above.

These examples illustrate the potential for novel pedagogical approaches to increase students' knowledge of science and their ability to think critically – knowledge that is indispensable to making informed judgements on socioscientific issues (Kolsto et al. 2006).

Changes to teaching practice, combined with an active engagement of the public and a more honest and thorough attempt to communicate the processes and pitfalls of science, hold real potential for benefit to the public. The advantages gained from scientific understanding extend far beyond the paranormal; science literacy is indispensable in the very normal, but profoundly important day-to-day choices faced by the consumer and voter.

REFERENCES

Aarnio K, Lindeman M (2005) Paranormal beliefs, education, and thinking styles. Pers Indiv Differ 39:1227-1236

Adams KE, Cohen, MH, Eisenberg D, Jonsen AR (2002) Ethical considerations of complementary and alternative medical therapies in conventional medical settings. Ann Intern Med 137:660-664

Borchelt RE (2001) Communicating the future. Sci Commun 23:194-211

Boyle C (2007) She told them boy was dead. 18 January 2007, New York Daily News. Available from http://global.factiva.com [accessed 13 January 2007]

CBS (Canadian Biotechnology Secretariat) (2005) Canada-US Survey on Biotechnology. Ottawa

Christopher K (2003) 'Miss Cleo' settles with the Federal Trade Commission. Skep Inq 27(2):8

Coll RK, Taylor N (2004) Probing scientists' beliefs: how open-minded are modern scientists? Int J Sci Educ 26:757-778

Davis GE, Bryson CL, Yueh B, McDonell MB, Micek MA, Fihn SD (2006) Treatment delay associated with alternative medicine use among veterans with head and neck cancer. Head Neck 28:926-931

DOCEP (Department of Consumer and Employment Protection) (2005) New 'psychic' scam announced., Available from http://www.docep.wa.gov.au/Corporate/Media/statements/2005/August/psychic_scam.html [accessed 23 February 2007]

Dougherty MJ (2004) Educating believers. Skeptic 10:31-35

Eisenberg DM, Davis RB, Ettner SL, Appel S, Wilkey S, van Rompay M (1998) Trends in alternative medicine use in the United States, 1990-1997. J Amer Med Assoc 280:1569-1575

Eve RA, Dunn D (1989) High school biology teachers and pseudoscientific belief: passing it on? Skep Inq 13:260-263

Gatowski SI, Dobbin SA, Richardson JT, Ginsburg GP, Merlino ML, Dahir V (2001) Asking the gatekeepers: a national survey of judges on judging expert evidence in a post-Daubert world. Law Human Behav 25:433-458

Goodman GE, Thornquist MD, Balmes J, Cullen MJ, Meyskens FL, Omenn GS, Valanis B, Williams JH (2004) The beta-carotene and retinol efficacy trial: Incidence of lung cancer and cardiovascular disease mortality during 6-year follow-up after stopping beta-carotene and retinol supplements. J Natl Cancer Inst 96:1743-1750

Gray T (1984) University course reduces belief in the paranormal. Skep Inq 8:247-251

Henney JE (2000) Risk of drug interactions with St John's wort. J Amer Med Assoc 283:1679-1679

Johnson M, Pigliucci M (2004) Is knowledge of science associated with higher skepticism of pseudoscientific claims? Am Biol Teach 66:536-544

Keene ML (1997) The psychic mafia. Prometheus, New York

Kolsto SD, Bungum B, Arnesen E, Isnes A, Kristensen T, Mathiassen K (2006) Science students' critical examination of scientific information related to socioscientific issues. Sci Educ 90:632-655

Lee A, Chui PT, Aun CST, Lau ASC, Gin T (2006) Incidence and risk of adverse perioperative events among surgical patients taking traditional Chinese herbal medicines. Anesthesiology 105:454-461

Leung W (2006) Ghosts in B.C.? You better believe it: Poll reveals British Columbians are a superstitious bunch. 30 October 2006, Vancouver Sun. Available from http://global.factiva.com/ [accessed 31 January 2007]

Lilienfeld SO, Lohr JM, Morier D (2001) The teaching of courses in the science and pseudoscience of psychology: useful resources. Teach Psych 28(3):182-191

Lindeman M, Aarnio K (2006) Paranormal beliefs: their dimensionality and correlates. Eur J Personality 20:585-602

Maddalena V, Thomas-Bernard W, Etowa J, Marsh-Jarvis P, Davis-Murdoch S, Smith D (2006) Cancer care and use of complementary and alternative medicine and home remedies in Nova Scotia's black community. J Palliat Care 22:246-246

Maienschein J (1999) To the future: arguments for scientific literacy. Sci Commun 21:75-87

Martin M (1994) Pseudoscience, the paranormal, and science education. Sci Educ 3:357-371

Meijerman I, Beijnen JH, Schellens JHM (2006) Herb-drug interactions in oncology: Focus on mechanisms of induction. Oncologist 11:742-752

Miller JD (2004) Public understanding of, and attitudes toward, scientific research: what we know and what we need to know. Public Underst Sci 13:273-294

Moon S (2007) Beware the bogus psychics. 13 February 2007, This is Money. Available from_http://www.thisismoney.co.uk/consumer/article.html?in_article_id=417387&in_page_id=5 [accessed 12 January 2008]

Moore DW (2005) Three in four Americans believe in paranormal. 16 January 2005, Gallup News Service. Available from http://www.gallup.com/poll/16915/Three-Four-Americans-Believe-Paranormal.aspx [accessed 02 August 2008]

Morier D, Keeports D (1994) Normal science and the paranormal: the effect of a scientific method course on students beliefs. Res High Educ 35(4):443-453

Neuhouser ML, Patterson RE, Schwartz SM, Hedderson MM, Bowen DJ, Standish LJ (2001) Use of alternative medicine by children with cancer in Washington State. Prev Med 33:347-354

NSB (National Science Board) (2000) Science and Engineering Indicators 2000. National Science Foundation, Arlington, VA

NSB (2004). Science and Engineering Indicators 2004. National Science Foundation, Arlington, VA

NSB (2006). Science and Engineering Indicators 2006. National Science Foundation, Arlington, VA

Radford B (2000) New York jury finds alternative medicine doctor negligent in patient's death. Skep Inq 24:5

Ramsay C, Walker M, Alexander J (1999) Alternative Medicine in Canada. Fraser Institute, Vancouver, BC

Randi J (1982) Flim-Flam! Psychics, ESP, unicorns and other delusions. Prometheus Books, New York

Research!America/Sigma Xi (2001) Survey of Sigma Xi Texas membership, Alexandria, VA. Available from http://www.researchamerica.org

Sagan C (1997) The demon haunted world: science as a candle in the dark. Ballantine Books, New York

Shermer M (1997) Why people believe weird things: pseudoscience, superstition, and other confusions of our time. WH Freeman & Co, New York

Woods PJ (1984) Evidence for the effectiveness of a reading program in changing beliefs in the paranormal. Skep Inq 9:67-70

Wesp R, Montgomery K (1998) Developing critical thinking through the study of paranormal phenomena. Teach Psych 25:275-278

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2006 NSIS UNDERGRADUATE STUDENT PRIZE WINNING PAPER

TURMERIC: NOT SO SPICY AFTER ALL

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Turmeric, also known as saffron Indian, prepared from the rhizome of *Curcuma longa* L. has an aromatic pepper-like, but somewhat bitter taste and gives curry dishes their characteristic yellowish colour. Curcumin, a non-toxic constituent of turmeric is responsible for the yellow colour, but importantly also has pharmacological potential. Many trials investigating the efficacy of curcumin against cancer, Alzheimer's disease, cystic fibrosis and human immunodeficiency virus (HIV) among others have been carried out *in vitro* with encouraging results. These findings point to the antioxidant properties of curcumin as an important factor in its effectiveness. The problem of retention *in vivo*, however, and thus its bioavailability, is a major negative aspect which requires much further study.

Le curcuma, aussi appelé safran des Indes, produit à partir du rhizome de *Curcuma longa,* a un goût aromatique ressemblant à celui du poivre, mais quelque peu amer. C'est lui qui donne au curry sa couleur jaune caractéristique. Cette couleur jaune vient de la curcumine, une composante non toxique du curcuma, qui a par-dessus tout un potentiel pharmacologique. De nombreuses expériences *in vitro* entreprises pour étudier l'efficacité de la curcumine contre le cancer, la maladie d'Alzheimer, la mucoviscidose et le virus de l'immunodéficience humaine (VIH), entre autres, ont produit des résultats encourageants. Elles semblent indiquer que les propriétés antioxydantes de la curcumine jouent un rôle important dans son efficacité. Toutefois, le problème de la rétention *in vivo*, de la substance, et donc sa biodisponibilité, représente un facteur négatif majeur, nécessitant de bien plus amples études.

INTRODUCTION

Natural products often serve as a rich source of relatively non-toxic compounds with pronounced biological effects. Curcumin is one; a phytochemical that has been established as a lead molecule for the development of novel therapies for various pathological conditions, such as cancer (Sharma et al. 2005), Alzheimer's disease (Lim et al. 2001), cystic fibrosis (Zeitlin 2004), human immunodeficiency virus (De Clercq 2000, Mazumder et al. 1997), chronic inflammation (Lim et al. 2001), and oxidative stress (Kopani et al. 2006). Curcumin underwent clinical trials for cancer because of its prominent activity as an antitumor and preventive agent (NCI 1996). This trial, however, ceased because of the poor bioavailability of the molecule (Sharma et al. 2001, Shoba et al. 1998). Currently clinical trials are underway to test the efficacy of curcumin against Alzheimer's disease (NIA 2006)

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and cystic fibrosis (Ramsey 2005). Intense efforts are being undertaken to modify the structure of curcumin to increase its bioavailability and potency while maintaining the relatively non-toxic nature of the natural product. This review is a summary and recapitulation of the important scientific findings and developments regarding curcumin and its biological activities, chemical properties, and pharmacokinetics; the anticancer and chemopreventive (prevention of illness through pharmaceutical means) aspects of curcumin's bioactivity have been reviewed by Sharma et al. (2005).

Curcumin, or diferuloylmethane [1,7-bis-(4-hydroxy-3-methoxyphenyl)-1,6-heptadiene-3,5-dione] is a polyphenol derived from the dried, ground rhizome of *Curcuma longa* L., a perennial herb and a member of the ginger family, known as turmeric in English, haldi in Hindi and ukon in Japanese. *Curcuma* spp contain turmerin, essential oils, and the phenolytic curcuminoids. The orange-yellow curcumin is the active ingredient in this commonly used spice (Sharma et al. 2005) which has long been used as a dye and therapeutic agent in Ayurveda, the traditional system of Indian medicine, to treat biliary disorders, anorexia, coryza, cough, diabetic wounds, hepatic disorder, rheumatism, and sinusitis (Sharma et al. 2005, Araujo & Leon 2001).

CHEMICAL PROPERTIES

Curcumin which is a bis-α,β-unsaturated β-diketone in equilibrium with its enol tautomer (Fig 1) contains three acidic hydrogen atoms in the form of two phenolic groups and an active methylene, which permit multiple modes for free radical scavenging activity. In neutral or acidic pH, or in the cell membrane, the bis-keto form (Fig 1a) exists predominately. The haptadienone linkage between the two methoxyphenol rings results in a highly activated carbon and the C-H bonds are very weak as a result of the delocalization of the unpaired electron on the adjacent oxygen atoms. Owing to these effects, curcumin acts as a powerful proton donor at pH 3-7. The heptatrienone structure (Fig 1b) is the major constituent in pH values above 8, and curcumin acts mainly as an electron donor, resulting in scavenging activity typical of phenolic antioxidants (Sharma et al. 2005).

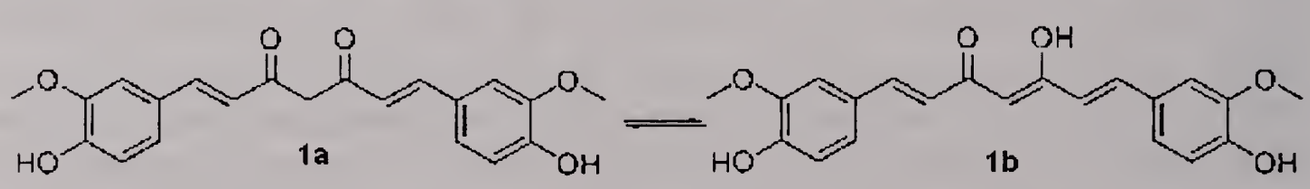


Fig 1 Tautomerism of curcumin with pH: 1a) bis-keto form (neutral or acidic pH values, 1b) heptatrienone form (values above pH 8)

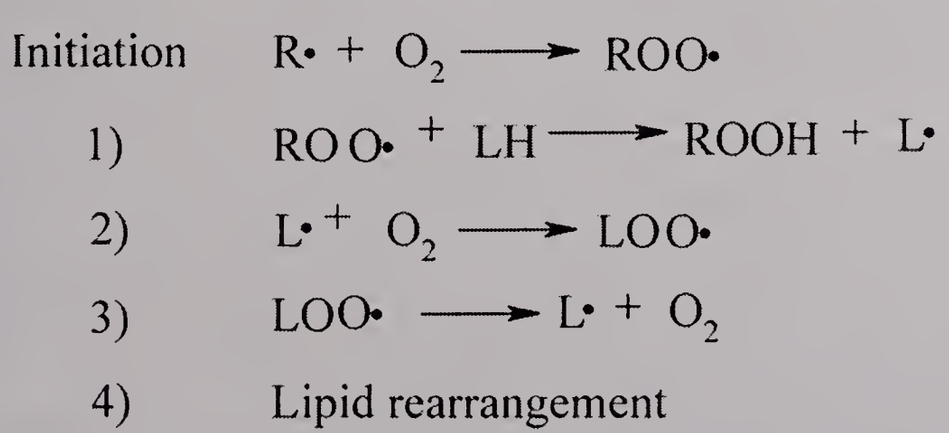
Antioxidant Activity

Curcumin derives its chemoprevention properties, at least in part, from its potent antioxidant behaviour (Lim et al. 2001). Research regarding oxidative

stress in the body suggests that natural polyphenols possess strong activity and curcumin stands at the forefront of the list of powerful antioxidants (Masella et al. 2005). Curcumin has been reported to significantly lower the concentration of reactive oxygen species (ROS) and reactive nitrogen species (RNS) in the body by scavenging mechanisms (Lim et al. 2001). Many pathological conditions such as atherosclerosis, hypertension, ischemia-reperfusion injury, inflammation, cystic fibrosis, cancer, type-2 diabetes, Parkinson's disease, and Alzheimer's disease have strong relations to increased levels of oxidative stress (Jezek & Hlavata 2005). Oxidative stress stems from an increase in ROS and RNS to levels that are potentially harmful to biological molecules such as DNA, proteins, and lipids. Typical ROS are superoxide anions, hydroxyl radicals, and hydrogen peroxide, whereas common RNS include the nitric oxide radical and the nitrogen dioxide radical; excess ROS and RNS are detoxified by the action of various antioxidant machinery in normal, healthy cells. Superoxide dismutase (SOD), catalase, and glutathione peroxidase (GPX) are examples of typical antioxidant enzymes (Jezek & Hlavata 2005).

ROS are often generated during metabolism, during the body's inflammatory reaction mechanism, through various lifestyle stressors such as cigarette smoking, and in tandem with physiological conditions such as ischaemia (Kopani et al. 2006). RNS are observed to be a product of L-arginine and L-citrulline breakdown via nitric oxide synthase and as a side product associated with the inhalation of automobile exhaust (Drew & Leeuwenburgh 2002).

Another important aspect of the antioxidant properties of curcumin is the prevention of lipid peroxidation (Araujo & Leon 2001) which plays a critical role in the inflammation experienced in heart disease and cancer. The most common lipids to undergo peroxidation are polyunsaturated fatty acids (PUFA); this cyclic process generally occurs in four steps: 1) proton transfer from the PUFA to the initiating radical or chain carrying peroxyl radicals; 2) reaction of the created lipid radical with molecular oxygen, yielding a lipid peroxyl radical; 3) separation of the lipid peroxyl radical to give oxygen and a lipid radical; and 4) rearrangement of the peroxyl radical (Scheme 1).



Scheme 1 Cyclic process of lipid peroxidation

These steps give polymeric materials, complex products including hydroperoxides, and cleavage products such as aldehydes which implement cytotoxic and genotoxic effects (gene damage) leading to the development of various pathological conditions (Niki et al. 2005). Curcumin, by acting as a powerful antioxidant, removes these peroxyl radicals from the biological system which effectively stops the lipid peroxidation chain reaction in the first step (Araujo & Leon 2001).

Apoptotic Activity (Programmed Cell Death)

Apart from antioxidant activity, curcumin also exhibits the ability to induce apoptosis mechanisms (programmed cell death in which the cell death is regulated at the molecular level and does not cause the contents of dying cells to be exposed as in the familiar type of cell death labelled as necrosis). Curcumin-induced apoptosis, has been shown to occur in cancer cells without cytotoxic effects on healthy cells (Duvoix et al. 2005); it appears to be tissue dependant and includes several mitochondrial associated mechanisms (Sharma et al. 2005).

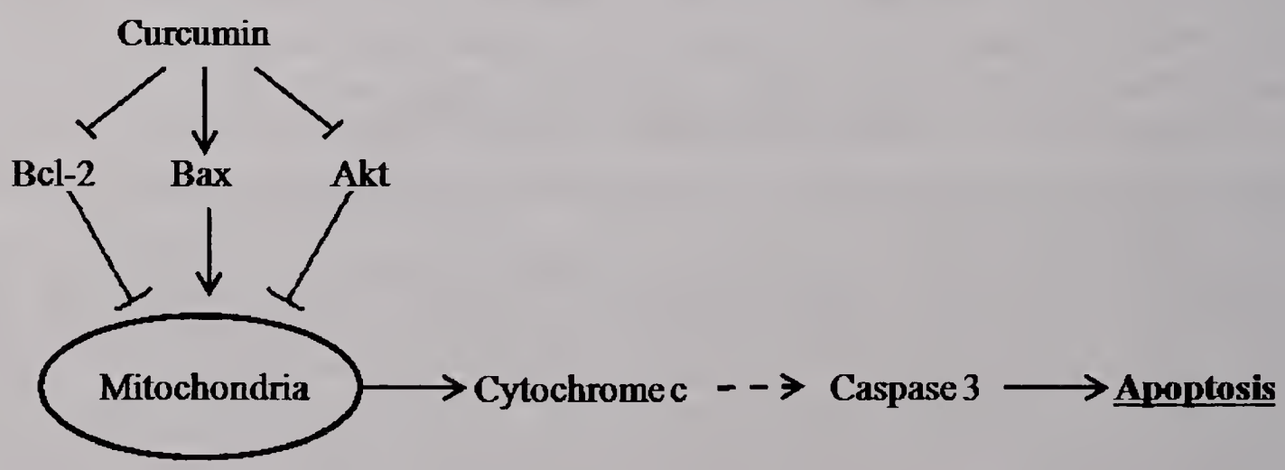


Fig 2 Overview of curcumin induced apoptosis.

Woo et al. (2003) have shown that curcumin-induced apoptosis of human renal carcinoma Caki tissue culture cells is directly linked to the sequential dephosphorylation of Akt (also known as protein kinase B, a serine/threonine kinase), release of cytochrome *c*, and activation of caspase 3 (a proteolytic enzyme that cleaves cysteine-aspartate linkages), and promotion of pore formation in the mitochondrial membranes (Woo et al. 2003, Conrad 2006). By dephosphorlyating Akt, curcumin effectively allows cytochrome *c* release from the mitochondria through the mitochondrial pore which is a key step in curcumin-induced apoptosis. Cytochrome *c* effectively activates caspases during the apoptotic response - an essential step because the caspases are close mediators of the apoptotic reaction (Woo et al. 2003).

Pore formation is regulated by the Bax and Bcl-2 protein families. Ultimately, these proteins establish the cell's response to various apoptotic stimuli. Curcumin significantly reduces the level of the antiapoptotic pro-

teins Bcl-2 and Bcl-X_L in the treated cells, allowing for increased action by the proapoptotic protein Bax (Woo et al. 2003). Pal et al. (2001) have also reported that in Ehrlich's Ascites carcinoma cells the apoptotic effects of curcumin are not a result of the down-regulation of the antiapoptotic protein Bcl-2, but by the up-regulation of the proapoptotic protein Bax. The general increase in the overall ratio of Bax/Bcl-2 leads to equivalent results, i.e. curcumin-induced apoptosis.

SPECIFIC DISEASE-RELATED ACTIVITIES

Alzheimer's Disease

Alzheimer's disease (AD) has been characterized by the accumulation of amyloid β peptide (Aβ), oxidative damage, and inflammation (Lim et al. 2001, Yang et al. 2005). Aβ is derived from the amyloid precursor protein (APP) through consecutive proteolysis by the aspartyl protease β-secretase and presenilin-dependent γ-secretase cleavage. It is believed that this accumulation of Aβ is one of the essential triggering factors initiating a cascade of events such as neurotoxicity, oxidative damage, and inflammation, leading to the progression of AD. Currently, clearance or prevention of Aβ is the central target for many AD therapeutic agents (Yang et al. 2005).

Curcumin, as previously discussed, is a potent antioxidant through the scavenging of free radicals. This activity effectively protects the brain from damage as a result of lipid peroxidation, ROS, and NO-based radicals (Lim et al. 2001). High levels of interleukin-1β are often associated with inflammation reactions in the brain. Curcumin has been shown to successfully down-regulate nuclear factor kappa B (NF-κB)-mediated transcription of inflammatory cytokines, inducible nitric oxide synthase, and cyclooxygenase 2. These results can be directly linked with the anti-inflammatory properties associated with curcumin treatment of AD. Assessing protein carbonyl formation is a technique used to detect oxidative damage to the brain (Lim et al. 2001). Protein carbonyls are formed from direct oxidation of amino acid side chains by ROS or lipid peroxidation products. This oxidation can result in the direct loss of function of the protein. Therefore, protein carbonyl levels are capable of serving as biomarkers for general oxidative stress (Zusterzeel et al. 2000). Curcumin has been shown to greatly suppress the levels of protein carbonyls in the brain, which is consistent with curcumin's known antioxidant capabilities.

High concentrations of metal ions, e.g. Cu (II), have also been associated with AD. Curcumin has been shown to be an effective Cu (II) chelating agent comparable in magnitude to that of clioquinol, an efficient Cu (II) chelating agent with promising treatment effects for moderately severe AD patients. This 1:2 Cu (II) to curcumin complex (2, Fig 3) has four phenolic hydroxyl groups that participate in the ROS-scavenging characteristics typical of curcumin. This complex has been shown to be less reactive than the parent curcumin molecule in scavenging ROS via the H-atom donating

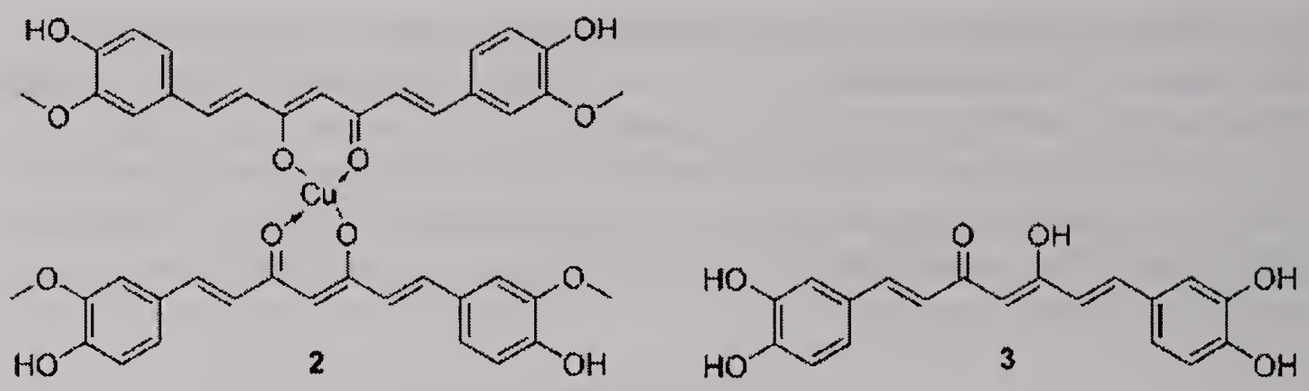


Fig 3 Curcumin-Cu (II) complex (2) and dicaffeoylmethane (3).

mechanism but more active through electron donation (Shen et al. 2005). These findings indicate curcumin acts via several modes to combat AD.

Cystic Fibrosis

Cystic fibrosis (CF) is a result of a dysfunctional cystic fibrosis transmembrane conductance regulator (CFTR) (Davis & Drumm 2004). The CFTR is a cyclic adenosine 3'5' monophosphate (cAMP)-activated chloride channel expressed in the apical membranes of many epithelia (Tabary et al. 2006). CF can lead to different pathological problems in various tissues, but the most prominent morbidity and mortality occurs when the disease is present in the airways. Dysfunction of CFTRs in this region leads to reduced water content, increased bacteria retention, and the severe inflammatory response associated with increased levels of bacteria. Restoration of the normal function of the mutant forms of the CFTR could restore normal lung function and normal life expectancy (Davis & Drumm 2004).

CF is most commonly associated with mutation in the ΔF508 allele. In CF patients, this allele is missing the codon for the amino acid, phenylalanine, in the first nucleotide-binding fold. This mutation causes the protein to misfold and become ubiquinated i.e., linked to ubiquitin, a small protein which marks proteins for destruction by proteasomes (i.e. large multiprotein complexes that catalyze the ATP-dependent breakdown of a variety of ubiquitin-linked proteins) (Davis & Drumm 2004). In CF patients with a mutation in the ΔF508 allele, there is incidence also of increased and prolonged activity of NF-κB, which is associated with the transcription of various inflammatory cytokines (Tabary et al. 2006). Possible mechanisms of action of curcumin-mediated restoration of ion exchange in ΔF508 CF patients involve the requirements of calcium for both destruction and increased inflammatory response (Courtney et al. 2004). The proteasomes responsible for the destruction of the CFTR protein are calcium dependent and by decreasing the concentration of calcium, the amount of ubiquinated protein would also decrease (Davis & Drumm 2004). As this mechanism has not been proven, it remains speculative. Tabary et al. (2006), however, have

shown that calcium is a key regulator of NF-κB activation and by regulating calcium levels it is possible to control the action of NF-κB.

It has been reported that when ΔF508 CF mice were administered curcumin orally, they regained normal nasal potential-difference measurements, indicating normal ion transfer; these mice were less likely to die through intestinal plugging (a result of inadequate salt and water transport into the gut) (Davis & Drumm 2004). These results, however, could not be reproduced by Dragomir et al. (2004), indicating the need for further investigation.

Anti-HIV Activity

Human immunodeficiency virus type 1 (HIV-1) and 2 (HIV-2) are both causative agents of acquired immunodeficiency syndrome (AIDS) (Mazumder et al. 1997). HIV-1 is the more common and virulent of the two, with HIV-2 having a longer latency period, fewer immunological abnormalities in individuals that are asymptomatic, and lower sexual transmission and perinatal rates than is associated with HIV-1 (Reid et al. 2005). HIV type 1 and 2 are retroviruses that offer a unique replication mechanism that provides many potential targets for chemotherapeutic intervention. Three key enzymes are evident in the replication of the retrovirus, post-infection: 1) the deoxyribonucleic acid (DNA) polymerase, reverse transcriptase (RT), is used to transcribe the viral ribonucleic acid (RNA) to proviral DNA prior to incorporation into the host DNA; 2) to catalyze 3'-preprocessing of the viral DNA and its insertion into the host DNA, the enzyme integrase (IN) is used; and 3) processing new viral particles is controlled by the enzyme HIV protease (PR). The current standard clinical treatment for HIV infection and AIDS is a combination of inhibitors of the RT and PR. Targets of these mechanisms, however, do not effectively remove the virus from the host and it is therefore desirable to investigate other targets of action, *i.e.* the HIV IN enzyme, as it occurs early in the lifecycle of the virus (Vajragupta et al. 2005).

Curcumin is a reported IN inhibitor with a 50% inhibition concentration (IC_{50}) of 40μM, while that of the curcumin analogue, dicaffeoylmethane (see 3 in Fig 3) is under 10μM (Mazumder et al. 1997). Vajragupta et al. (2005) used computational docking to simulate models of the interaction of curcumin with IN and PR. Similar binding mechanisms with the active sites of both IN and PR were modelled. Results obtained in this study indicate that the keto-enol tautomerization of curcumin (see Fig 1a, b) and both *o*-hydroxyl structures are important for inhibition of the PR protein, while the keto-enol and only one side of the *o*-hydroxyl exhibited tight binding during inhibition of the IN protein. The binding mechanisms obtained by this simulation provide potential targets for future modification of curcumin.

Anti-Inflammatory Activity

Chronic inflammation can last for long periods (weeks, months or years) as a result of the persistence of the causative inflammatory stimulus. Chronic inflammation can lead to tissue damage and has been reported to

predispose the patient to cancer as indicated by the association between inflammatory bowel disease and colon cancer, chronic pancreatitis and pancreatic adenocarcinoma, and hepatitis with hepatocellular carcinoma (Baniyash 2006).

Possible chemopreventive agents in response to chronic inflammation involve downregulation of tumor necrosis factor-α (TNF-α), interleukin-1 (IL-1), NF-κB (Sharma et al. 2005), and cyclooxygenase-2 (COX-2) (Lim et al. 2001), increasing levels of SOD and GPX (Manikandan et al. 2004), and act as a potent antioxidant. Evidently, curcumin possesses mechanisms of action that complement all of the chemopreventive methods put forth; indicating curcumin is an excellent prototype for chemotherapy of both chronic inflammation and cancer.

Pharmacokinetics

Although curcumin exhibits many potentially beneficial characteristics, it has not yet become a clinical solution to any pathological conditions because of its poor pharmacokinetic properties. Initially, it was found that curcumin administered in the diet of rats was excreted mainly in the feces (Sharma et al. 2001). When administered orally to rats, curcumin, again, appeared to be mainly excreted in the feces, along with metabolites such as curcumin sulphate and curcumin glucuronide in the urine and plasma, along with smaller levels of reduced products such as dihydrocurcumin, tetrahydrocurcumin, hexahydrocurcumin and hexahydrocurcuminol. Preclinical studies using suspensions of isolated human hepatocytes, liver or gut microsomes suggest that curcumin is metabolically reduced within minutes. Another study indicated that co-administration of piperine with curcumin may increase the bioavailability of curcumin by as much as 154% by inhibiting xenobiotic glucuronidation (Shoba et al. 1998).

As shown in rodents, curcumin essentially undergoes intestinal metabolism resulting in low bioavailability. Any absorbed curcumin appears to undergo rapid fast-pass metabolism and excretion in the bile (Sharma et al. 2001). The consequence of these mechanisms is that curcumin is unable to perform *in vivo* the biological activity observed in *in vitro* studies.

CONCLUSIONS

It is clear curcumin holds promise in the development of new therapies for cancer, Alzheimer's disease, cystic fibrosis, inflammation, and HIV infection. Although curcumin possesses wide ranging anti-inflammatory and anti-cancer properties its low systemic bioavailability upon oral dosing limits the tissues it can reach at concentrations sufficient to be effective. In view of the pharmacological properties reported, however, "its clinical evaluation in individuals at risk of developing cancer, especially of the gastrointestinal tract, appears opportune" (Sharma et al. 2005).

REFERENCES

Araujo CAC, Leon LL (2001) Biological activities of *Curcuma longa* L. Mem I Oswaldo Cruz 96:723-728

Baniyash M (2006) Chronic inflammation, immunosuppression and cancer: New insights and outlook. Semin Cancer Biol 16:80-88

Conrad DM (2006) Clear as mud: the type I/type II model for death receptor-induced apoptosis. Proc NS Inst Sci 43(2):201-209

Courtney JM, Ennis M, Elborn JS (2004) Cytokines and inflammatory mediators in cystic fibrosis. J Cystic Fibrosis 3:223-231

Davis PB, Drumm ML (2004) Some like it hot: curcumin and CFTR. Trends Mol Med 10:473-475

De Clercq E (2000) Current lead natural products for the chemotherapy of human immunodeficiency virus (HIV) infection. Med Res Rev 20:323-349

Dragomir A, Bjorstad J, Hjelte L, Roomans GM (2004) Curcumin does not stimulate cAMP-mediated chloride transport in cystic fibrosis airway epithelial cells. Biochem Biophys Res Commun 322:447-451

Drew B, Leeuwenburgh C (2002) Aging and the role of reactive nitrogen species. Ann NY Acad Sci 959 66-81

Duvoix A, Blasius R, Delhalle S, Schnekenburger M, Morceau F, Henry E, Dicato M, Diederich M (2005) Chemopreventive and therapeutic effects of curcumin. Cancer Lett 223:181-190

Jezek P, Hlavata L (2005) Mitochondria in homeostasis of reactive oxygen species in cell, tissues, and organism. Int J Biochem Cell Biol 37:2478-2503

Kopani M, Celec P, Danisovic L, Michalka P, Biro C (2006) Oxidative stress and electron spin resonance. Clin Chim Acta 364:61-66

Lim GP, Chu T, Yang FS, Beech W, Frautschy SA, Cole GM (2001) The curry spice curcumin reduces oxidative damage and amyloid pathology in an Alzheimer transgenic mouse. J Neurosci 21:8370-8377

Manikandan P, Sumitra M, Aishwarya S, Manohar BM, Lokanadam B, Puvanakrishnan R (2004) Curcumin modulates free radical quenching in myocardial ischaemia in rats. Int J Biochem Cell Biol 36:1967-1980

Masella R, Di Benedetto R, Varec; R, Filesi C, Giovannini C (2005) Novel mechanisms of natural antioxidant compounds in biological systems: involvement of glutathione and glutathione-related enzymes. J Nutr Biochem 16:577-586

Mazumder A, Neamati N, Sunder S, Schulz J, Pertz H, Eich E, Pommier Y (1997) Curcumin analogs with altered potencies against HIV-1 integrase as probes for biochemical mechanisms of drug action. J Med Chem 40:3057-3063

NIA (National Institute of Aging) (2006) Curcumin in patients with mild to moderate Alzheimer's disease. http://clinicaltrials.gov/show/NCT00099710

NCI (National Cancer Institute) (1996) Clinical Development Plan: Curcumin. J Cell Biochem 26S:72-85

Niki E, Yoshida Y, Saito Y, Noguchi N (2005) Lipid peroxidation: Mechanisms, inhibition, and biological effects. Biochem Biophys Res Commun 338:668-676

Pal S, Choudhuri T, Chattopadhyay S, Bhattacharya A, Datta GK, Das T, Sa G (2001) Mechanisms of curcumin-induced apoptosis of Ehrlich's ascites carcinoma cells. Biochem Biophys Res Commun 288:658-665

Ramsey B (2005) Safety study of orally administered curcuminoids in adult subjects with cystic fibrosis. http://www.clinicaltrials.gov/ct/show/NCT00219882

Reid P, MacInnes H, Cong ME, Heneine W, Garcia-Lerma JG (2005) Natural resistance of human immunodeficiency virus type 2 to zidovudine. Virology 336:251-264

Sharma RA, Gescher AJ, Steward WP (2005) Curcumin: The story so far. Eur J Cancer 41:1955-1968

Sharma RA, McLelland HR, Hill KA, Ireson CR and 6 others (2001) Pharmacodynamic and pharmacokinetic study of oral curcuma extract in patients with colorectal cancer. Clin Cancer Res 7:1894-1900

Shen L, Zhang H-Y, Ji H-F (2005) A theoretical study on Cu(II)-chelating properties of curcumin and its implications for curcumin as a multipotent agent to combat Alzheimer's disease. J Mol Struct: THEOCHEM 757:199-202

Shoba G, Joy D, Joseph T, Majeed M, Rajendran R, Srinivas PS (1998) Influence of Piperine on the Pharmacokinetics of Curcumin In Animals and Human Volunteers. Planta Med 64:353-356

Tabary O, Boncoeur E, de Martin R, Pepperkok R, Clement A, Schultz C, Jacquot J (2006) Calcium-dependent regulation of NF-[kappa]B activation in cystic fibrosis airway epithelial cells. Cell Signal 18:652-660

Vajragupta O, Boonchoong P, Morris GM, Olson AJ (2005) Active site binding modes of curcumin in HIV-1 protease and integrase. Bioorg Med Chem Lett 15:3364-3368

Woo JH, Kim YH, Choi YJ, Kim DG and 8 others (2003) Molecular mechanisms of curcumin-induced cytotoxicity: induction of apoptosis through generation of reactive oxygen species, down-regulation of Bcl-X-L and IAP, the release of cytochrome c and inhibition of Akt. Carcinogenesis 24:1199-1208

Yang FS, Lim GP, Begum AN, Ubeda OJ and 7 others (2005) Curcumin inhibits formation of amyloid beta oligomers and fibrils, binds plaques, and reduces amyloid in vivo. J Biol Chem 280:5892-5901

Zeitlin P (2004) Can curcumin cure cystic fibrosis? New Engl J Med 351:606-608

Zusterzeel P, Mulder T, Peters W, Wiseman S, Steegers E (2000) Plasma protein carbonyls in nonpregnant, healthy pregnant and preeclamptic women. Free Rad Res 33:471-476.

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NOVA SCOTIAN INSTITUTE OF SCIENCE
SESSION 2006-2007

PRESIDENT'S REPORT

During the past year, members of the Institute have actively engaged in furthering its mandate of promoting science in Nova Scotia. This has been achieved in seven ways, namely by:

- presenting a program of public lectures given by expert Nova Scotian scientists,
- publishing the peer-reviewed Proceedings of the Nova Scotian Institute of Science,
- providing financial support for Regional Science Fairs,
- maintaining a library
- running the annual scientific writing competition,
- running a mentorship program for university science students, and
- developing and actively maintaining the Institutional web site at www.chebucto.ns.ca/Science/NSIS.

During the past year, the lecture program of six public lectures was organized by Mary-Jane O'Halloran; all but one of the lectures were held at the Nova Scotia Museum of Natural History and the Institute is indebted to the Museum for its continued support. Council surveyed members of the Institute especially for their comments on the lecture program and as a result particular attention was paid to make attractive the titles and abstracts provided by speakers. This, coupled with effective publicity organized by Sandra Nowlan, resulted in the lectures being well-attended. Lectures in the fall were presented by Todd Hatchette (Department of Pathology, QE II Health Sciences Centre), "Avian Influenza: the coming pandemic" and Boris Worm (Department of Biology, Dalhousie University), "Large marine predators in the World's Oceans: how to save our most endangered wildlife".

The lecture planned for December had to be cancelled at the last minute due to a significant snow storm and resultant power outage at the Museum. However, the lecturer scheduled for January had to postpone his talk and was replaced by the December lecturer, Daniel O'Halloran (O'Halloran Campbell Consultants Ltd), who described "The Halifax Harbour Cleanup Project" to a large and attentive audience in the Alumni Hall at the University of King's College.

The winter/spring lecture programme was completed by Eric Mills (Department of Oceanography, Dalhousie University), "Learning from Europe: A.G.Huntsman and the new direction of Canadian marine sciences", Marc Mansour (ImmunoVaccine Technologies Inc., Halifax), "Therapeutic vaccines: from university to market" and, to a full house, John Calder (N.S.

Department of Natural Resources), "Coal Age Galapagos: Joggins and the quest for World Heritage status".

For the past several years, the Proceedings have been published under the very able editorship of Dr James E. Stewart who has maintained a high standard. He has been assisted by a dedicated Editorial Board. Jim has informed Council that he wishes to retire in the near future and Council has a process in place to ensure continuity in this important institutional activity. The Institute is indebted to Dr Stewart and to members of the Editorial Board for their services.

The annual Science Writing Competition was organized again this year by Ken Adams. Despite a considerable effort publicizing the competition, most of a promising list of potential entries did not materialize, with only three essays being submitted by the published deadline. One essay arrived several weeks after the deadline and in fairness to the other contestants, this late entry was not accepted. The essay by Jason Loxton (Dalhousie University Earth Sciences graduate student) was judged to be prize-winning in the Science Writing Category and the essay by Benjamin H. Rotstein (King's and Dalhousie undergraduate student) was judged to merit Honourable Mention in the same category.

The Institute has again provided financial support to the ten Regional Science Fairs in Nova Scotia and Sean Tibbetts has continued to run the mentorship program which matches students with working scientists. The Institute provided financial support to the Northeast Biological Graduate Student Conference, which was used to fund four prizes for excellent student presentations in different categories. In other activities, the Institute cosponsored with the Ecology Action Centre the 2007 Symposium on Sable Island at St Mary's University and cosponsored the first Canadian IRIS/SSA Distinguished Lecture with the Dalhousie University Department of Earth Sciences. The 2007 Canada-wide Science Fair will be held in Truro NS in May and members of the Institute will be assisting in this important event.

In conclusion, members of the Institute are undoubtedly aware that its mission of presenting and promoting science, especially research, can only be achieved by continued activity on the part of members by serving on Council and taking part in other activities of the Institute. As with all similar volunteer organizations, there is a need for younger members to become active as older members retire. The Institute has a long and proud history and will celebrate 150 years of promoting science to Nova Scotians in 2012, five years hence. Few other Canadian organizations can boast this track record and it will be appropriate if members can begin planning some modest celebrations to mark this event. Finally, I thank all members of Council for their diligence and hard work during the past year.

Respectfully submitted to the AGM
May 7, 2007
J. Stuart Grossert
President NSIS

APPENDIX: MONTHLY LECTURES

October 2: *Avian influenza: the coming pandemic.*
Todd Hatchette, Department of Pathology, QE II Health Sciences Centre

November 6: *Large marine predators in the world's oceans: how to save our most endangered species.*
Boris Worm, Department of Biology, Dalhousie University

December 4: Cancelled due to storm

January 8: *The Halifax Harbour cleanup project.*
Daniel O'Halloran, O'Halloran Campbell Consultants Ltd.

February 5: *Learning from Europe: AG Huntsman and the new direction of Canadian marine Sciences.*
Eric Mills, Department of Oceanography, Dalhousie University

March 5: *Therapeutic vaccines: from university to market.*
Marc Mansour, ImmunoVaccine Technologies Inc.

April 2: *Coal Age Galapagos: Joggins and the quest for World Heritage status.*
John Calder, NS Department of Natural Resources

May 7: *Extracting energy from the wind*
Charles Demond, Pubnico Wind Farms

LIBRARIAN'S REPORT

There are currently one hundred and eighty-seven NSIS exchange partners. One institution, Universitetsbiblioteket i Trondheim, cancelled their exchange program with us over the past year. The number of institutional members remains unchanged from last year and continues to be twenty-seven. Invoices were sent out in February 2007 for institutional memberships and to date we have received payment for eighteen renewals.

In August 2006 volume 43, Part 2, of the Proceedings of the Nova Scotian Institute of Science was published. The Library mailed the issue to exchange partners and institutional members. In addition, we also did the mailing to personal members. Postal charges for distribution of the printed journal cost the Institute $1,813.55 in 2006.

The Flora of Nova Scotia by A.E. Roland was reprinted in 2005 and has a new one-volume format with spiral binding. We have 15 copies remaining, of the 50 printed, and they are priced at $35.00. Sales of past volumes of the Proceedings during 2006/2007 generated $706.50 in revenue. (See Appendix A (attached) for details.)

At the April 2007 Council meeting the NSIS Librarian, Sharon Longard, introduced the idea of having past volumes of the Proceedings of the Nova Scotian Institute of Science digitized and made available electronically online. There is currently a Digital Initiatives Committee in the Dalhousie University Libraries and they are looking for proposals of suitable digitization projects. The NSIS Librarian, working with other librarians at Dalhousie, would like to submit a Pilot Project Proposal to digitize volume 1, 1863-1866 and volume 2, 1867-1870 of the Proceedings. Council supported this proposal in principle, but Mrs. Longard was asked to obtain additional information re: access to the material and NSIS rights.

Publications continue to be received regularly from our 187 active exchange partners and this material is added on an ongoing basis to the collection. I would like to thank Carol Richardson and the Serials Department staff in the Killam Library who ensure that the NSIS Library operations continue to function smoothly.

Respectfully submitted,
May 7, 2007
Sharon Longard

LIBRARIAN'S REPORT

APPENDIX

Sales of Proceedings June 2006 – March 2007

Qty	Date	Issue	Price
1	June 2006	Proceedings of the Nova Scotian Institute of Science v 19 pt 4	$5.00
1	June 2006	Forest Aphidae of Nova Scotia	$5.00
1	June 2006	The vegetation and phytogeography of Sable Island	$7.50
1	June 2006	Chondrus crispus	$5.00
1	June 2006	A forest classification for the Maritime Provinces v 25 pt 2	$5.00
1	June 2006	The birds of Sable Island	$7.50
1	June 2006	The Lepidoptera of Nova Scotia	$5.00
1	August 2006	Proceedings of the Nova Scotian Institute of Science v 42 pt 1	$22.00 + $2.50 shipping
14	September 2006	Flora of Nova Scotia	$35.00 = $490.00
1	September 2006	Proceedings of the Nova Scotian Institute of Science v 42 pt 1	$22.00 + 2.50 shipping
1	September 2006	Proceedings of the Nova Scotian Institute of Science v 42 pt 1	$22.00 + 2.50 shipping
2	October 2006	Proceedings of the Nova Scotian Institute of Science v 42 pt 1	$22.00 = $44.00
1	January 2007	Proceedings of the Nova Scotian Institute of Science v 42 pt 1	$22.00 + 2.50 shipping
1	January 2007	Proceedings of the Nova Scotian Institute of Science v 25 pt 2	$5.00
1	February 2007	Proceedings of the Nova Scotian Institute of Science v 42 pt 1	$22.00
1	March 2007	Proceedings of the Nova Scotian Institute of Science v 27 pt 1	$5.00 + $2.50 shipping
30			$706.50

EDITOR'S REPORT

The Proceedings of the Nova Scotian Institute of Science Volume 43 Part 2 was published in August 2006. This 177-page issue included the 6 papers of the written Symposium on Marine Sciences. This symposium described much of the background, development and purpose of marine geology, oceanography and fisheries science in government institutes in the Atlantic area and was focused largely on activities at the Bedford Institute of Oceanography, Dartmouth, NS.

In addition, the issue contained 5 prize-winning papers from the 2005 competition of the Nova Scotian Institute of Science: Student Science Awards. These 5 papers formed an eclectic and interesting array covering the topics of Apoptosis (i.e. programmed cell death), Latent Semantic Indexing, the enzyme Phenylalanine Ammonia Lyase, a Design Study for Scintillation Counters and an essay on Rational Drug Design. We were pleased to note that these originated at 4 different academic institutions, Dalhousie University, Cape Breton University, St. Mary's University and the University of King's College. The issue also includes the report on the NSIS 2004-5 season.

Preparation of Volume 44 Part 1 is well in hand. Publication by the coming summer is anticipated with distribution taking place before the 2007/2008 NSIS season.

Respectfully submitted to the AGM
May 7, 2007
James E. Stewart
Editor NSIS

TREASURER'S REPORT

ASSETS:			
Bank Account	$5,939.50		
Petty Cash	0.00		
		5,939.50	
Investments		54,084.13	
			59,986.48
Account Receivable			**60,023.63**
LIABILITIES AND NET WORTH:			
Accounts Payable (Science Fair cheques)			-200.00
Rental (Museum)			-175.00
Total Liabilities and Net Worth			**59,648.63**
INVESTMENTS:			
Cash Balance			10.29
CIBC Premium T-Bill (short-term)			15,677.84
CIBC Investment Certificate A @4.40% (due Apr 2008)			8,396.00
Can Western Bank Certificate A@3.30% (due May 2007)			10,000.00
Laurention Bank Certificate A @3.675% (due May 2009)			10,000.00
Laurention Bank Certificate A @4.500% (due June 2010)			10,000.00
			54,084.13
REVENUE			
Membership Dues			
Individuals	$1830.00		
Institutions	252.90		
AGM (2006)	1020.00		
Donations/Grant	1026.25		
Sales/Page charges			
Proceedings	5264.17		
Other	549.00		
GST Rebate/Interest	1963.24		
	$11,905.56 Total		
EXPENDITURES			
Advertisement/promotion	$159.61		
AGM (2006)	1135.21		
Office supplies	37.19		
Proceedings printing	6977.50		
Postage	1957.88		
Donations/Prizes	1250.00		
	11,517.59 Total		

Net: $387.97

Treasurer's Report (Continued)

Notes

Finances

The Institute's finances remain stable with a net worth of 59,648.63. Revenue included a NS museum grant ($1000) and a rebate for GST paid during the last 4 years amounting to $1959.92.

Under expenditures, Donations/prizes of $1250 include $100 donations to each of 10 regional science fairs in Nova Scotia and a $250 donation to the 14th annual Northeast Biological Graduate Student Conference held at Dalhousie University.

Membership

We collected $1830 in membership dues in 2006-2007. Membership sits at 133 including 4 Life members.

Respectfully submitted to the AGM
May 7, 2007 (prepared March 31, 2007)
H. Stephen Ewart
Treasurer NSIS

PROC. N.S. INST. SCI. (2008)
Volume 44, Part 2, pp. 231-238

REVISED BYLAWS OF THE NOVA SCOTIAN INSTITUTE OF SCIENCE

(approved at the Annual General Meeting May 5, 2008)

(Established in 1862 as an unincorporated Society and incorporated in 1890 by Chapter 123 of the Statutes of the Province of Nova Scotia.)

NAME AND OBJECTIVES

1. The name of the Society is the Nova Scotian Institute of Science.

2. The objectives of the Society are to represent and promote science. This is done by holding regular public meetings, by publication of work in its *Proceedings*, by maintaining a library of journals and databases, and a website which includes a Hall of Fame.

MEMBERSHIP

Classes and Eligibility

3. There shall be five classes of membership: ordinary, life, student, honorary and institutional.

4. Any person supporting the objectives of the Society is eligible for ordinary membership and shall become an active member upon payment of the annual dues to the Treasurer.

5. Any student of a recognized educational institution is eligible for student membership and shall become an active member upon payment of the annual dues to the Treasurer.

6. Any member distinguished in some branch of science or who has rendered conspicuous service to the advancement of science in Nova Scotia, or to the affairs of the Institute, is eligible for nomination and election as an honorary member. Nominations must be submitted to the Council in writing, be signed by three (3) members in good standing, and be accompanied by a document presenting the reasons for awarding the honour. Election of candidates shall require the support of a majority of Council members.

7. Subject to approval by Council, any institution is eligible for institutional membership.

Privileges

8. Ordinary, life, honorary, and student members may vote or hold office.

9. Members of all classes will have the following rights and privileges:

a. to participate in any meeting of the Institute;
b. to submit papers for presentation to the Institute subject to approval by Council;
c. to receive a copy of the *Proceedings* while in good standing.

Fees

10. Honorary members shall not be required to pay a fee.

11. The fees for ordinary, life, student, and institutional members, which will include payment for publications, shall be proposed by Council to the members, in writing, at least fourteen (14) days prior to the Annual General Meeting for approval by a majority vote of the members present at the Annual General Meeting. Annual fees for ordinary and student members shall be due and payable on September 1 of each year, or upon becoming a member. If membership is begun after March 31 of a given year, fees shall not be due again until September 1 of the following year. An invoice for fees owing, together with details of the Lecture Program for the year, will be mailed to non-institutional members each September.

12. Ordinary members in good standing may become life members by paying a fee of $300.00.

Non-Payment of Fees

13. Members who are two (2) years in arrears in payment of their fees shall cease to be members. Only members who are in good standing shall receive printed copies of the *Proceedings*.

14. Anyone who has ceased to be a member by reason of non-payment of fees may at the discretion of the Council be re-admitted as a member upon payment of the annual fee. Any back issues of the *Proceedings* required shall be paid for in full.

OFFICERS

15. The officers of the Institute shall consist of a President, a Vice-President, a Past-President, a Secretary, a Treasurer, a Publicity Officer, a Membership Officer, an Editor, a Librarian and a Webmaster. In some cases, one individual may hold two offices.

16. The officers, except the Librarian, shall be elected each year at the Annual General Meeting of the Institute and shall hold office until the next Annual General Meeting or until their successors are elected. The tenure of officers except the Librarian and the Editor, should not exceed five (5) years.

17. The Librarian is appointed from among the Science Librarians at Dalhousie University, where the NSIS collection is housed and shall serve until a successor has been appointed.

18. A Nominating Committee shall consist of the President, Past-President and a third member approved by Council at least one (1) month before the date of the Annual General Meeting.

19. The Nominating Committee shall present in writing, at the Annual General Meeting, nominations for:

    a. officers (except the Librarian);
    b. other members of Council;
    c. auditor(s) or appropriate person(s) to review the accounts of the Institute; should no nominations be made, Council may appoint such person(s);
    d. and nominees to government commissions.

    No member shall be nominated unless their consent has been received by the Nominating Committee.

    Notwithstanding that the Librarian has a continuing appointment and that the Editor may serve for more than 5 years, the Nominating Committee shall, as a courtesy, consult annually with both the Librarian and Editor. Further nominations for the officers and other members of the Council to be elected at the Annual General Meeting may be made at the meeting by any two (2) ordinary members, but the consent of any member so nominated must have been obtained before they are nominated.

20. Election shall be by a show of hands unless a ballot is requested by the majority present.

Duties of Officers

21. Officers shall, in addition to the performance of such duties as are incident to their office and of such duties as may be assigned to them from time to time by the Council, have the following duties and responsibilities:

President

22. The President shall:
    a. preside at meetings of Council, at general meetings open to the public, and at other meetings of members;
    b. be responsible for the general administration of the affairs of the Institute, subject to the direction of Council;
    c. prepare an annual report of the Institute; and
    d. serve on the Nominating Committee.

Vice-President

23. The Vice-President shall act in the place of the President if and when the President is not able to act. Normally, the Vice-President will chair a Committee to prepare a list of speakers for the Lecture Program for the next year, to be approved by Council before the Annual General Meeting.

Past-President

24. The Past-President shall:
    a. act in the place of the President if neither the President nor the Vice-President is able to act; and
    b. chair the Nominating Committee.

Secretary

25. The Secretary shall:
    a. keep the minutes of Council and other meetings of the Institute, including the Annual General Meeting;
    b. deal with the correspondence of the Institute, including maintaining a duplicate list of members, as provided by the Treasurer and issuing notices of meetings of members and of Council.

Treasurer

26. The Treasurer shall:
    a. keep the records and receipts of all monies of the Institute;
    b. ensure that all expenditures have been duly authorized and are evidenced by proper receipts and vouchers;
    c. coordinate the annual review of the Institute's finances by person(s) chosen according to Paragraph 19c;
    d. present to the Annual General Meeting of the Institute a balance sheet and statements of income and expenditures as well as a report of the financial review;
    e. maintain a list of members and their status such that members may be billed each year for the fee owing;
    f. bill members each year for the current fee, and keep the Council informed regularly of the overall financial situation of the Institute;
    g. be responsible, under the direction of the Council, for the general management of the finances of the Institute;
    h. file appropriate financial statements with governments.

Publicity Officer

27. The Publicity Officer shall publicize the activities of the Institute by sending notices to the news media.

Membership Officer

28. The Membership Officer shall:
    a. in conjunction with the Treasurer and the Secretary maintain a list of members and their addresses;
    b. distribute information about the Institute to new and potential members;
    c. promote membership in the Institute.

Librarian

29. The Librarian shall:
    a. respond to requests from individuals to purchase issues of the *Proceedings* or acquire articles;
    b. send out annual invoices to Institutional Members;
    c. keep a current mailing list of Institutional Members and Exchange Partners for distributing the *Proceedings*;
    d. conduct correspondence of the Institute arising from the mailing of the *Proceedings* to Institutional Members and Exchange Partners;
    e. submit a Repertoire Payment Form to Access Copyright annually;
    f. attend monthly Council meetings;
    g. prepare an Annual Report for presentation at the Annual General meeting.

Editor

30. The Editor shall be responsible and have the authority for the editorial administration of the *Proceedings*, as determined by the Editorial Board and the Council.

Webmaster

31. The Webmaster shall:
    a. under general direction from the Council, actively maintain the Website of the Institute so that all information posted on institutional activities is current, and
    b. arrange the Website so that it serves as the major source of information for both members and nonmembers on all Institutional functions.

Council

32. The Council of the Institute shall consist of the Officers of the Institute and four (4) to six (6) other members to be elected as provided by these by-laws at the Annual General Meeting. If there are more than two (2) vacancies in the Council at any time, the Council may fill these vacancies and any person so appointed to fill a vacancy shall hold office until the next Annual General Meeting.

    Each Local Chapter shall be represented on Council by an additional member designated by the Chapter.

    Council may invite representatives from other organizations that support the objectives of the Institute as non-voting observers on Council.

33. The Council shall be responsible for the general management of the affairs of the Institute, subject to these by-laws and according to policies established by Council.

34. The Council shall consider and decide on nominations for admission to the web-based Hall of Fame based on recommendations from a Committee that includes the Librarian, another member of Council and at least one other member with expertise in the scientific area of the nominee. Nominees shall be deceased scientists of distinction, who had a tangible connection to Nova Scotia.

MEETINGS

Members

35. The Annual General Meeting of the members of the Institute shall normally be held in May of each year.

36. Regular monthly meetings of the members shall be held from October to April, inclusive. Special meetings of members shall be held at such time or times as the Council may determine.

37. The Council shall be responsible for formulating the Lecture Program for the regular monthly meetings, see paragraph 23.

38. In addition to the consideration of matters relating to the management of the affairs of the Institute, the Lecture Program shall consist of the presentation of original research, scientific demonstrations, lectures on scientific topics, or such other matters as the Council may determine from time to time. Council may delegate the responsibility of soliciting presentations and accepting or rejecting submissions for presentations.

39. Members shall be given at least ten (10) days notice of meetings of the Institute. In special circumstances, the Council may prescribe a shorter notice period.

40. Ten (10) ordinary members of the Institute shall constitute a quorum for meetings of members.

COUNCIL

41. Meetings of Council shall be held at such time as the Council may direct and, failing such direction, at such time or times as the President, or in his or her absence or inability to act, the Vice-President or Past-President, may determine.

42. At least ten (10) days notice shall be given of meetings of the Council or, in special circumstances, a meeting may be called with shorter notice.

43. Seven (7) members of the Council shall constitute a quorum for meetings of the Council.

PUBLICATIONS

44. The *Proceedings* and other publications of the Institute shall be the responsibility of an Editorial Board comprising the Editor, as Chair, and at least four (4) other members approved by Council.

45. The Editorial Board shall be responsible for establishing the policies and formats of the publications of the Institute.

FINANCES

46. The Council shall be responsible for administration of the monies and funds of the Institute.

47. The operation of the Society shall be carried on without purpose of gain for its members. Any profits or other accretions to the Institute shall be used in promoting its objectives.

48. As determined by Council, the funds of the Institute shall be deposited in an account with an insured financial institution in Canada or invested in a money market fund or certificate guaranteed by the Canadian government, a province of Canada, a chartered bank in Canada, or a trust company in Canada.

49. Monies may be transferred between accounts and investments by the Treasurer, but monies may only be withdrawn by cheques authorized by two (2) officers of the Council, normally, the Treasurer and either the President or the Vice-President. Council shall approve annually no more than four members of Council to have signing authority for the Institute.

50. The finances of the Institute shall be audited annually by persons chosen according to Paragraph 19c. A financial review shall normally be submitted for approval at the Annual General Meeting. If, in a given year, the financial review has not been completed by that time, the results will be sent to members electronically before June 30.

LOCAL CHAPTERS

51. Members of the Institute residing in areas outside the Halifax Regional Municipality may apply in writing to Council for the privilege of establishing a Local Chapter. On approval, Council will arrange for the allocation to the Local Chapter of a portion of the annual dues of each member of the Institute registered as a member of the Local Chapter. Each Local Chapter shall elect its own officers and arrange its own meetings and activities in conformity with the objectives and by-laws of the Institute. Each Chapter shall designate its own representative to Council.

AMENDMENTS

52. The By-laws of the Institute may be amended by the affirmative vote of two-thirds of the members present and voting at the Annual General Meeting or at a Special Meeting of the Institute provided that notice of such meeting containing the nature of the proposed amendment or amendments is distributed to all members at least fourteen (14) days prior to the meeting. Proposals for amendments should be signed by at least ten (10) members of the Institute, or have secured the support of the Council prior to distribution to the membership.

53. The Council may at any time authorize the calling of a special meeting of members to consider proposed amendments to the By-laws. On receipt of a requisition in writing signed by at least ten (10) members of the Institute and containing proposed amendments, Council shall call a special meeting of members for the consideration of such amendments.

Instructions to Authors

The *Proceedings of the Nova Scotian Institute of Science* publishes papers in English or French. Manuscripts must be typewritten double-spaced with 4 cm margins. Disk copies in Word or WordPerfect are preferred, but must also be accompanied by three paper copies of the manuscript. An abstract of no more than 200 words, free of formulae, must be included at the beginning of the paper, followed by key words or phrases. This should be followed by an introduction, methods, results or observations, discussion and references. In some cases a combination of these sections may be more effective. Underline only material to be set in italics, and use capital letters only when the letters or words should appear in capitals in the printed paper. Layout and style should follow that used in recent volumes. Each page of the manuscript should be numbered, the first page carrying only the title, authors' names and affiliations and any necessary footnotes. Spelling should follow that of Webster's Third New International Dictionary. Abbreviations, nomenclature, and symbols for units of measurements should follow international recommendations. SI units should be used whenever possible. Use day-month-year sequence for dates. Do not use periods after abbreviations. Photographs should be mounted on Bristol board ready for reproduction. Prints must be of high quality on glossy paper with no space between those mounted in groups. Color illustrations will be accepted at the discretion of the Editor. The cost of color reproduction is borne fully by the authors who must submit a statement accepting this responsibility. References are to be collected at the end of the paper and referred to in the text by inclusion of the author's name and year of publication. The list of references should be consistent with the following examples:

Periodicals	Nielsen KJ, Franz DR (1995) The influence of adult conspecific and shore level on recruitment of the ribbed mussel *Geukensia demissa* (Dillwyn). J Exp Mar Biol Ecol 188:89-98
Books	Cushing D, Walsh J (1976) The ecology of the seas. WB Saunders Company, Toronto
Papers from books or symposium proceedings	Lee GF (1975) Role of hydrous metal oxides in the transport of heavy metals in the environment. In: Krenkel PA (ed) Heavy metals in the aquatic environment. Pergamon, Oxford, p 137-147
Pers. comm.	Smith AJ (2001) (Nova Scotia Department of Agriculture, Halifax) Personal communication

Tables should be numbered consecutively in bold-faced Arabic numerals and must have brief titles that are self-explanatory; each table must be typed on a separate page.

Illustrations are to be numbered consecutively in Arabic numerals. Captions should be self-explanatory and typed on a separate page. Two paper copies of each are required even when they are embedded in an electronic file. All lines in drawings must be of suitable thickness to reproduce well when published in the *Proceedings*. Similarly, letters and symbols in drawings should be at least 2 mm high when reduced to the size used in the *Proceedings*.

Page Charges. Currently a charge of $25 per page is levied to help defray the cost of publication. This amount is charged to the institution or a contract supporting the research reported in the published paper. In no case will acceptance of the paper be dependent upon payment of the page charges.

Authors are responsible for editing the galley proofs. Orders for reprints, in addition to the 15 supplied gratis to the corresponding author, must be received when the galley proof is returned.

Papers should be sent to the Editor:

Dr. Peter G. Wells,
15 Westgate Drive
Halifax, NS, Canada B3P 1T7
E-mail: oceans2@ns.sympatico.ca

Recommandations aux auteurs

Le *Proceedings of the Nova Scotian Institute of Science* publie des articles en anglais ou en français. Les documents soumis doivent être dactylographiés à double interligne avec des marges de 4 cm. On préfère recevoir le texte sur disquette en format de traitement de mot Word ou WordPerfect ainsi que trois copies imprimées. Au début de l'article, on exige un résumé n'excédant pas 200 mots, sans formules et suivi de mots ou d'expressions clés. Cette partie devrait être suivie par l'introduction, les méthodes, les résultats ou observations, la discussion et les références bibliographiques. En certain cas, il sera peut-être plus efficace de combiner quelques parties. Soulignez seulement ce qui devrait paraître en caractères italiques et écrivez avec une majuscule seulement ce qui devrait être imprimé en majuscule. Les détails de présentation et de style devraient suivre un numéro récent de la publication. Chaque page de l'article devrait être numérotée et la première page ne portera que le titre, les noms d'auteurs, leurs adresses respectives et toute note infrapaginale qui s'imposera. L'orthographe doit suivre Le Grand Robert et les accents doivent être insérés sur les majuscules. Les abréviations, la nomenclature et les symboles seront conforme aux recommandations internationales. Où possible, utilisez le Système international d'unités. N'ajoutez pas de point aux abréviations. Les photographies devraient être montées sur une carte Bristol prêtes à reproduire. Les épreuves doivent être de qualité supérieure et aucune espace devrait séparée une collage d'un groupe de photographies. Les illustrations en couleurs seront acceptées comme l'éditeur scientifique jugera à propos. Les coûts de reproduction en couleurs seront aux frais des auteurs qui devront émettre une déclaration acceptant cette responsabilité. Les références bibliographiques devraient paraître à la fin de l'article et devraient être citées dans le texte à l'aide des noms d'auteurs et de l'année de publication. Veuillez, s'il vous plait, abréger les titres des journaux selon le 'BIOSIS Serial Source', dernière édition, et respecter strictement le format PNSIS (voir les exemples suivants).

Périodiques	Nielsen KJ, Franz DR (1995) The influence of adult conspecific an shore level on recruitment of the ribbed mussel Geukensia demissa (Dillwyn). J Exp Mar Biol Ecol 188: 89-98
Livres	Cushing D, Walsh J (1976) The ecology of the seas. WB Saunders Company, Toronto
Articles de livres ou de compte rendu	Lee GF (1975) Role of hydrous metal oxides in the transport of heavy metals in the environment. In: Krenkel PA (ed) Heavy metals in the aquatic environment. Pergamon, Oxford, p 137-147
Communication personnelle	Smith AJ (2001) (Nova Scotia Department of Agriculture, Halifax) Personal communication

Les tableaux doivent étre numérotés de façon continue en chiffres arabes et en caractères gras. Chacun doit comporter un bref titre qui s'explique de soi même et doit être dactylographié sur une page distincte.

Les illustrations sont numérotées en chiffres arabes selon leur ordre séquentiel. Les légendes devraient s'expliquer de soi même et devraient être dactylographiées sur une page distincte. On exige deux copies imprimées de chaque illustration même quand elle fait partie d'un fichier électronique. L'épaisseur des lignes sur une illustration doit être suffisante pour que la reproduction soit nette à la grandeur de la publication. De façon semblable, le lettrage et les symboles des illustrations devraient être au moins 2 mm de haut quand elles paraîtront dans le Proceedings.

Frais de publication. Des frais de 25,00 $ par page sont présentement imposés afin de subvenir une portion des frais de publication. Ce montant est imputé à l'institution ou au contrat qui appuie la recherche présentée dans l'article. L'acceptation de l'article pour publication ne reposera jamais sur le paiement des frais de publication.

Les auteurs sont responsables pour la revue des épreuves en placard. On doit recevoir les commandes pour des tirés à part, en plus des 15 qui sont fournies gratuitement à l'auteur correspondant(e), quand vous retournerez les épreuves à placard.

Soumettez vos articles à l'editeur scientifique:

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15 Westgate Drive
Halifax, NS, Canada B3P 1T7
E-mail: oceans2@ns.sympatico.ca